

**Arsenic Removal from Drinking Water by Coagulation/Filtration
U.S. EPA Demonstration Project at
Village of Waynesville, IL
Final Performance Evaluation Report**

by

**Abraham S.C. Chen[‡]
Angela M. Paolucci[§]
Brian J. Yates[§]
Lili Wang[‡]
Vivek Lal[§]**

[§]Battelle, Columbus, OH 43201-2693
[‡]ALSA Tech, LLC, Powell, OH 43065-6082

**Contract No. EP-C-05-057
Task Order No. 0019**

for

**Thomas J. Sorg
Task Order Manager**

**Water Supply and Water Resources Division
National Risk Management Research Laboratory
Cincinnati, Ohio 45268**

**National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268**

DISCLAIMER

The work reported in this document was funded by the United States Environmental Protection Agency (EPA) under Task Order 0019 of Contract EP-C-05-057 to Battelle. It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Any opinions expressed in this paper are those of the author(s) and do not, necessarily, reflect the official positions and policies of the EPA. Any mention of products or trade names does not constitute recommendation for use by the EPA.

FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

ABSTRACT

This report documents the activities performed and the results obtained from the arsenic removal drinking water treatment technology demonstration project at the Village of Waynesville, IL. The main objective of the project was to evaluate the effectiveness of the Peerless coagulation/filtration (C/F) system, using GreensandPlus™ filtration media with an anthracite cap, in removing arsenic to meet the new arsenic maximum contaminant level (MCL) of 10 µg/L. Additionally, this project evaluated (1) the reliability of the treatment system, (2) the required system operation and maintenance (O&M) and operator skill levels, and (3) the capital and O&M cost of the technology. The project also characterized the water in the distribution system and process residuals produced by the treatment process. The types of data collected during the demonstration period included system operation, water quality (both across the treatment train and in the distribution system), process residuals, and capital and O&M cost.

The community water system at Waynesville, IL served approximately 450 residents. The system was supplied by two wells, i.e., Wells No. 6 and 8, with a combined flowrate of approximately 84 gal/min (gpm). Source water contained 33.1 µg/L of total arsenic, 2,298 µg/L of total iron, and 33.1 µg/L of total manganese. Because of the reducing condition with the source water (as reflected by 1.2 mg/L [on average] of dissolved oxygen [DO] and -31 mV [on average] of oxidation-reduction potential [ORP]), arsenic existed almost entirely as soluble As(III) and almost all iron and manganese were present in the soluble form. The source water also contained 3.8 mg/L (as N) of ammonia and 7.9 mg/L of total organic carbon (TOC). These elevated levels of ammonia and TOC made NaMnO₄ to be the oxidant of selection for oxidizing reducing species in the source water. The selection was confirmed with a series of jar tests using both KaMnO₄ (as a surrogate for NaMnO₄) and chlorine as oxidants.

The Peerless C/F system consisted of a NaMnO₄ addition system, four 36-in × 72-in carbon steel, epoxy-lined pressure vessels arranged in parallel, and three post-treatment chemical addition systems for chlorination, fluoridation, and polyphosphate addition. The addition of NaMnO₄ oxidized the reducing species such as soluble As(III), Fe(II), and Mn(II) and formed arsenic-laden iron particles prior to filtration. Each pressure filter contained 6 ft³ of quartz support gravel overlain with 14 ft³ of GreensandPlus™ filtration media and 7 ft³ of #1 anthracite cape. GreensandPlus™ has a silica sand core with a thermally-bonded manganese dioxide (MnO₂) coating. GreensandPlus™ is slightly different from the conventional manganese greensand, which is formulated from a glauconite greensand.

The system was designed for a total flowrate of 96 gpm, or 24 gpm/vessel, equivalent for a filtration rate of 3.4 gpm/ft². Actual flowrates through the filters averaged 11.4 gpm/vessel (or 40.5 gpm for the system) when only Well No. 6 was operating (since system startup on July 15, 2009, through December 17, 2009), or 22.1 gpm (or 84.4 gpm for the system) when both wells were operating (from December 18, 2009, through September 19, 2010). These flowrates yielded filtration rates no higher than 3.4 gpm/ft², which is just over the 10-state standard of 2 to 3 gpm/ft² as required by Illinois Environmental Protection Agency (IL EPA). Throughout the demonstration period, the system operated for 1,840 hr when only Well No. 6 was in operation, and for 1,601 hr when both wells were in operation. The respective average daily run times were 11.8 and 5.8 hr. The system treated approximately 12,603,800 gal of water with an average daily demand of approximately 29,400 gal during the 432-day performance evaluation study.

With 2,277 µg/L (on average) of soluble iron and 31.4 µg/L (on average) of soluble arsenic in source water, the iron to arsenic ratio was 72:1. With this ratio and the reducing condition maintained throughout the treatment train, oxidation of soluble As(III) and Fe(II) and formation of filterable arsenic-laden particles were ensured by the addition of 6.3 mg/L of NaMnO₄ (on average). After NaMnO₄ addition, soluble As(III) was converted almost entirely to particulate arsenic, leaving only 0.6 and 3.0 µg/L (on average) of soluble As(III) and As(V), respectively, in the oxidized water. Following

GreensandPlus™ filtration, arsenic and iron concentrations were reduced to below 4.6 and 34.9 µg/L (on average), respectively. Manganese concentrations in raw water were low, averaging 33.1 µg/L. The 6.3-mg/L NaMnO₄ dose rate appears to be sufficient to react with reducing species and form filterable MnO₂ particles, which were removed to below 100 µg/L by the GreensandPlus™ filters.

The presence of elevated dissolved organic matter (DOM) levels appears to have some impact on iron and manganese solids formation. Unlike what was observed at most other arsenic demonstration sites, addition of NaMnO₄ to the well water did not completely oxidize soluble Fe(II) to iron solids, leaving as much as 147 µg/L of soluble iron in the NaMnO₄-treated water. Also in the NaMnO₄-treated water was a significant amount of “soluble” manganese (ranging from 26.4 to 1567 µg/L and averaging 765 µg/L), which most likely existed as soluble Mn(II) (due to the formation of Mn(II)-DOM complexes) or colloidal MnO₂ particles (due to the presence of DOM). Additional contact time provided prior to the filter beds might have helped form filterable MnO₂ particles, which were subsequently removed by the GreensandPlus™ filters.

Backwash wastewater contained, on average, 432, 86,432, and 46,572 µg/L of arsenic, iron, and manganese, respectively. As expected, arsenic, iron, and manganese existed mainly in the particulate form. Total suspended solids (TSS) levels ranged from 105 to 1,701 mg/L and averaged 441 mg/L. Based on this TSS level and 3,100 gal of wastewater produced during each backwash event, approximately 11.4 lb (or 5,175 g) of solids would be discharged to the sewer. The solids would contain 0.01 lb (or 5.0 g) of arsenic, 2.2 lb (or 1,014 g) of iron, and 1.2 lb (or 547 g) of manganese.

The water quality in the distribution system was significantly improved after startup of the treatment system. Arsenic and iron concentrations were reduced from pre-startup levels of 23.4 and 977 µg/L (on average), respectively, to 8.8 and 168 µg/L (on average), respectively. These concentrations were higher than those in the filter effluent, indicating solubilization, destabilization, and/or desorption of arsenic-laden particles/scales in some segments of the distribution system. Manganese concentrations measured after system startup averaged 64.6 µg/L (on average), which was higher than that (i.e., 15.0 µg/L) measured before system startup, but lower than (i.e., 85.7 µg/L) in the filter effluent.

The total capital cost for the system was \$161,559, including \$90,750 for equipment, \$22,460 for site engineering, and \$48,350 for installation, startup, and shakedown. Using the system’s rated capacity of 96 gpm (138,240 gal/day [gpd]), the normalized capital cost was \$1,683/gpm (\$1.17/gpd). The total O&M cost was \$0.68/1,000 gal of treated water including the cost for NaMnO₄ addition, electricity consumption, and labor.

CONTENTS

DISCLAIMER	ii
FOREWORD	iii
ABSTRACT.....	iv
APPENDICES	vii
FIGURES.....	vii
TABLES	vii
ABBREVIATIONS AND ACRONYMS	ix
ACKNOWLEDGMENTS	xi
1.0 INTRODUCTION	1
1.1 Background.....	1
1.2 Treatment Technologies for Arsenic Removal	2
1.3 Project Objectives	2
2.0 SUMMARY AND CONCLUSIONS	6
3.0 MATERIALS AND METHODS.....	8
3.1 General Project Approach.....	8
3.2 System O&M and Cost Data Collection	9
3.3 Sample Collection Procedures and Schedules	10
3.3.1 Source Water.....	10
3.3.2 Treatment Plant Water	10
3.3.3 Backwash Wastewater and Solids	10
3.3.4 Distribution System Water.....	10
3.4 Oxidant Demand and Disinfection Byproducts Formation Potential Studies.....	12
3.4.1 Raw Water Sample Collection.....	12
3.4.2 Oxidant Demand Studies	13
3.4.3 Arsenic/Iron Removal and DBP Formation Potential Study	13
3.5 Sampling Logistics.....	14
3.5.1 Preparation of Arsenic Speciation Kits.....	14
3.5.2 Preparation of Sampling Coolers	15
3.5.3 Sample Shipping and Handling	15
3.6 Analytical Procedures	15
4.0 RESULTS AND DISCUSSION	16
4.1 Pre-existing Facility Description and Treatment System Infrastructure	16
4.1.1 Source Water Quality.....	16
4.1.2 Distribution System	21
4.2 Treatment Process Description	21
4.2.1 Technology Description.....	21
4.2.2 System Design and Treatment Process	23
4.3 System Installation.....	29
4.3.1 Permitting.....	29
4.3.2 Building Construction.....	29
4.3.3 Installation, Shakedown, and Startup.....	29
4.4 System Operation.....	34
4.4.1 Operational Parameters.....	34
4.4.2 Backwash	35
4.4.3 NaMnO ₄ Injection.....	36

4.4.4 Residual Management.....	37
4.4.5 System/Operation Reliability and Simplicity	37
4.5 Jar Test Results	39
4.5.1 Oxidant Demand Studies	39
4.5.2 Arsenic/Iron Removal and DBP Formation Potential Studies.....	39
4.6 System Performance	42
4.6.1 Treatment Plant Sampling.....	42
4.6.2 Backwash Wastewater and Solids Sampling	52
4.6.3 Distribution System Water Sampling	55
4.7 System Cost	58
4.7.1 Capital Cost.....	59
4.7.2 Operation and Maintenance Cost.....	60
5.0 REFERENCES	61

APPENDICES

APPENDIX A: OPERATIONAL DATA
APPENDIX B: ANALYTICAL DATA

FIGURES

Figure 4-1. Well No. 6 Pump House and Pre-existing Chemical Addition Systems	17
Figure 4-2. Well No. 8 Pump House and Piping	17
Figure 4-3. 50,000-gal Water Tower	18
Figure 4-4. Process Flow Diagram and Sampling Locations.....	24
Figure 4-5. NaMnO ₄ Addition System	26
Figure 4-6. Filtration Vessels and Valve Tree	26
Figure 4-7. System Instrumentation.....	27
Figure 4-8. Post-Treatment Chemical Addition Systems	28
Figure 4-9. Construction of New Treatment Plant Building.....	30
Figure 4-10. Layout of New Treatment Facility	31
Figure 4-11. Arrival and Offloading of System Components.....	32
Figure 4-12. Filtration Vessels Before and After Plumbing	32
Figure 4-13. NaMnO ₄ Dosage.....	36
Figure 4-14. Arsenic Speciation at Sampling Locations IN, AO, and TT (or TA).....	46
Figure 4-15. Total Iron Concentrations Across Treatment Train	48
Figure 4-16. Total Arsenic Concentrations Across Treatment Train.....	49
Figure 4-17. Total Manganese Concentrations Across Treatment Train.....	51

TABLES

Table 1-1. Summary of Rounds 1, 2, and 2a Arsenic Removal Demonstration Locations, Technologies, and Source Water Quality.....	3
Table 1-2. Number of Demonstration Sites Under Each Arsenic Removal Technology	5
Table 3-1. Pre-demonstration Activities and Completion Dates	8
Table 3-2. Evaluation Objectives and Supporting Data Collection Activities	9
Table 3-3. Sampling Schedule and Analytes.....	11

Table 3-4.	Oxidant Demand Study Experimental Matrix.....	13
Table 3-5.	Experimental Matrix for Arsenic/Iron Removal and DBP Formation Studies	14
Table 4-1.	Village of Waynesville Water Quality Data	19
Table 4-2.	Physical Properties of Filtration Media.....	22
Table 4-3.	Design Features of Peerless Anthracite/GreensandPlus™ Filtration System	25
Table 4-4.	Specifications of Flow Meters/Totalizers and Pressure Gauges	27
Table 4-5.	Freeboard Measurements During System Installation	33
Table 4-6.	System Punch-List Operational Issues.....	33
Table 4-7.	Summary of System Operational Parameters.....	34
Table 4-8.	Summary of System Backwash Parameters	36
Table 4-9.	Results of Chlorine Demand Study for Well No. 8 Raw Water.....	39
Table 4-10.	Results of Permanganate Demand Study for Well No. 8 Raw Water.....	40
Table 4-11.	Results for Arsenic/Iron Removal and DBPs Formation Potential Studies	40
Table 4-12.	Summary of Arsenic, Iron, and Manganese Analytical Results.....	43
Table 4-13.	Summary of Other Water Quality Parameter Results	44
Table 4-14.	Backwash Wastewater Sampling Results	53
Table 4-15.	ICP-MS Results of Backwash Solids Samples	56
Table 4-16.	Distribution Sampling Results	57
Table 4-17.	Summary of Distribution System Water Sampling Results	58
Table 4-18.	Capital Investment Cost for Peerless GreensandPlus™ System.....	59
Table 4-19.	Operation and Maintenance Cost for Peerless GreensandPlus™ System.....	60

ABBREVIATIONS AND ACRONYMS

AAL	American Analytical Laboratories
Al	aluminum
AM	adsorptive media
As	arsenic
ATS	Aquatic Treatment Systems
bgs	below ground surface
BL	baseline
Ca	calcium
Cl	chloride
C/F	coagulation/filtration
CWS	community water system
DBP	disinfection byproduct
DI	deionized
DO	dissolved oxygen
DOM	dissolved organic matter
DPD	N, N-diethyl-p-phenylenediamine
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
GFH	granular ferric hydroxide
gpd	gallons per day
gph	gallons per hour
gpm	gallons per minute
HAA5	haloacetic acids
HDPE	high-density polyethylene
HIX	hybrid ion exchanger
Hp	horsepower
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification
IL EPA	Illinois Environmental Protection Agency
IR	iron removal
IX	ion exchange
LCR	Lead and Copper Rule
MCL	maximum contaminant level
MDL	method detection limit
MEI	Magnesium Elektron, Inc.
Mg	magnesium

ABBREVIATIONS AND ACRONYMS (Continued)

Mn	manganese
MRDL	maximum residual disinfectant level
MRDLG	maximum residual disinfectant level goal
mV	millivolts
Na	sodium
NA	not analyzed
NaOCl	sodium hypochlorite
NRMRL	National Risk Management Research Laboratory
NS	not sampled
NTU	nephelometric turbidity unit
O&M	operation and maintenance
OIT	Oregon Institute of Technology
ORD	Office of Research and Development
ORP	oxidation-reduction potential
psi	pounds per square inch
PO ₄	orthophosphate
PLC	programmable logic controller
POU	point-of-use
QA	quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RO	reverse osmosis
RPD	relative percent difference
RFP	request for proposal
Sb	antimony
SDWA	Safe Drinking Water Act
SiO ₂	silica
SMCL	secondary maximum contaminant level
SO ₄ ²⁻	sulfate
STS	Severn Trent Services
TDH	total dynamic head
TDS	total dissolved solids
TOC	total organic carbon
TSS	total suspended solids
TTHM	total trihalomethanes
VOA	volatile organic analysis
VOC	volatile organic compound

ACKNOWLEDGMENTS

The authors wish to extend their sincere appreciation to Mr. Kenneth Rich and Mrs. Fran Garrett at the Village of Waynesville for their dedication in monitoring treatment system operations and collecting samples from the treatment and distribution systems throughout the demonstration period. Mr. William Brown of CMT Engineering interacted closely with the project team for system/site engineering during the design phase and system troubleshooting after system startup. Mr. Merle Loete, the operator of the water system at Geneseo Hills Subdivisioin in Geneseo, IL, traveled monthly to Waynesville, IL to perform treatment plant water sampling, arsenic speciation, and onsite water quality measurements. This performance evaluation study would not have been possible without their efforts.

1.0 INTRODUCTION

1.1 Background

The Safe Drinking Water Act (SDWA) mandates that the U.S. Environmental Protection Agency (EPA) identify and regulate drinking water contaminants that may have adverse human health effects and that are known or anticipated to occur in public water supply systems. In 1975, under the SDWA, EPA established a maximum contaminant level (MCL) for arsenic (As) at 0.05 mg/L. Amended in 1996, the SDWA required that EPA develop an arsenic research strategy and publish a proposal to revise the arsenic MCL by January 2000. On January 18, 2001, EPA finalized the arsenic MCL at 0.01 mg/L (EPA, 2001). In order to clarify the implementation of the original rule, EPA revised the rule text on March 25, 2003, to express the MCL as 0.010 mg/L (10 µg/L) (EPA, 2003). The final rule required all community and non-transient, non-community water systems to comply with the new standard by January 23, 2006.

In October 2001, EPA announced an initiative for additional research and development of cost-effective technologies to help small community water systems (<10,000 customers) meet the new arsenic standard, and to provide technical assistance to operators of small systems to reduce compliance costs. As part of this Arsenic Rule Implementation Research Program, EPA's Office of Research and Development (ORD) proposed a project to conduct a series of full-scale, on-site demonstrations of arsenic removal technologies, process modifications, and engineering approaches applicable to small systems. Shortly thereafter, an announcement was published in the *Federal Register* requesting water utilities interested in participating in Round 1 of this EPA-sponsored demonstration program to provide information on their water systems. In June 2002, EPA selected 17 out of 115 sites to host the demonstration studies.

In September 2002, EPA solicited proposals from engineering firms and vendors for cost-effective arsenic removal treatment technologies for the 17 host sites. EPA received 70 technical proposals for the 17 host sites, with each site receiving from one to six proposals. In April 2003, an independent technical panel reviewed the proposals and provided its recommendations to EPA on the technologies that it determined were acceptable for the demonstration at each site. Because of funding limitations and other technical reasons, only 12 of the 17 sites were selected for the demonstration project. Using the information provided by the review panel, EPA, in cooperation with the host sites and the drinking water programs of the respective states, selected one technical proposal for each site.

In 2003, EPA initiated Round 2 arsenic technology demonstration projects that were partially funded with Congressional add-on funding to the EPA budget. In June 2003, EPA selected 32 potential demonstration sites. In September 2003, EPA again solicited proposals from engineering firms and vendors for arsenic removal technologies. EPA received 148 technical proposals for the 32 host sites, with each site receiving from two to eight proposals. In April 2004, another technical panel was convened by EPA to review the proposals and provide recommendations to EPA with the number of proposals per site ranging from none (for two sites) to a maximum of four. The final selection of the treatment technology at the sites that received at least one proposal was made, again, through a joint effort by EPA, the state regulators, and the host site. Since then, four sites have withdrawn from the demonstration program, reducing the number of sites to 28.

With additional funding from Congress, EPA selected 10 more sites for demonstration under Round 2a. Somewhat different from the Round 1 and Round 2 selection process, Battelle, under EPA's guidance, issued a Request for Proposal (RFP) on February 14, 2007, to solicit technology proposals from vendors and engineering firms. Upon closing of the RFP on April 13, 2007, Battelle received a total of 44 proposals from 14 vendors, which were subsequently reviewed by a three-expert technical review panel convened at EPA on May 2 and 3, 2007. Copies of the proposals and recommendations of the review

panel were later provided to and discussed with representatives of the 10 host sites and state regulators in a technology selection meeting held at each host site from April through August 2007. The final selections of the treatment technology were made, again, through a joint effort by EPA, the respective state regulators, and the host sites. A 96-gal/min (gpm) coagulation/filtration (C/F) system using GreensandPlus[™] with an anthracite cap designed by Peerless, Inc. of Kalamazoo, MI, was selected for demonstration at the Village of Waynesville, IL.

As of July 2011, all 50 arsenic treatment systems were operational and performance evaluations for 49 systems were complete.

1.2 Treatment Technologies for Arsenic Removal

Technologies selected for Rounds 1, 2, and 2a demonstration included adsorptive media (AM), iron removal (IR), C/F, ion exchange (IX), reverse osmosis (RO), point-of-use (POU) RO, and system/process modification. Table 1-1 summarizes the locations, technologies, vendors, system flow rates, and key source water quality parameters (including As, iron [Fe], and pH). Table 1-2 presents the number of sites for each technology. AM technology was demonstrated at 30 sites, including four with IR pretreatment. IR technology was demonstrated at 12 sites, including four with supplemental iron addition. C/F, IX, and RO technologies were demonstrated at three, two, and one sites, respectively. The Sunset Ranch Development site that demonstrated POU RO technology had nine under-the-sink RO units. The Oregon Institute of Technology (OIT) site classified under AM had three AM systems and eight POU AM units. The Lidgerwood site encompassed only system/process modifications. An overview of the technology selection and system design for the 12 Round 1 demonstration sites and the associated capital costs is provided in two EPA reports (Wang et al., 2004; Chen et al., 2004), which are posted on the EPA Web site at <http://www.epa.gov/ORD/NRMRL/arsenic/resource.htm>.

1.3 Project Objectives

The objective of the arsenic demonstration program was to conduct full-scale performance evaluations of treatment technologies for arsenic removal from drinking water supplies. The specific objectives were to:

- Evaluate the performance of the arsenic removal technologies for use on small systems.
- Determine the required system operation and maintenance (O&M) and operator skill levels.
- Characterize process residuals produced by the technologies.
- Determine the capital and O&M cost of the technologies.

This report summarizes the performance of the Peerless C/F system at the Village of Waynesville, IL, from July 15, 2009, through September 19, 2010. The types of data collected during the demonstration period included system operation, water quality (both across the treatment train and in the distribution system), residuals, and capital and O&M cost.

**Table 1-1. Summary of Rounds 1, 2, and 2a Arsenic Removal Demonstration
Locations, Technologies, and Source Water Quality**

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
Northeast/Ohio							
Carmel, ME	Carmel Elementary School	RO	Norlen’s Water	1,200 gpd	21	<25	7.9
Wales, ME	Springbrook Mobile Home Park	AM (A/I Complex)	ATS	14	38 ^(a)	<25	8.6
Bow, NH	White Rock Water Company	AM (G2)	ADI	70 ^(b)	39	<25	7.7
Goffstown, NH	Orchard Highlands Subdivision	AM (E33)	AdEdge	10	33	<25	6.9
Rollinsford, NH	Rollinsford Water and Sewer District	AM (E33)	AdEdge	100	36 ^(a)	46	8.2
Dummerston, VT	Charette Mobile Home Park	AM (A/I Complex)	ATS	22	30	<25	7.9
Houghton, NY ^(c)	Town of Caneadea	IR (Macrolite)	Kinetico	550	27 ^(a)	1,806 ^(d)	7.6
Woodstock, CT	Woodstock Middle School	AM (Adsorbsia)	Siemens	17	21	<25	7.7
Pomfret, CT	Seely-Brown Village	AM (ArsenX ^{np})	SolmeteX	15	25	<25	7.3
Felton, DE	Town of Felton	C/F (Macrolite)	Kinetico	375	30 ^(a)	48	8.2
Stevensville, MD	Queen Anne’s County	AM (E33)	STS	300	19 ^(a)	270 ^(d)	7.3
Conneaut Lake, PA	Conneaut Lake Park	IR (Greensand Plus) with ID	AdEdge	250	28 ^(a)	157 ^(d)	8.0
Buckeye Lake, OH	Buckeye Lake Head Start Building	AM (ARM 200)	Kinetico	10	15 ^(a)	1,312 ^(d)	7.6
Springfield, OH	Chateau Estates Mobile Home Park	IR & AM (E33)	AdEdge	250 ^(e)	25 ^(a)	1,615 ^(d)	7.3
Great Lakes/Interior Plains							
Brown City, MI	City of Brown City	AM (E33)	STS	640	14 ^(a)	127 ^(d)	7.3
Pentwater, MI	Village of Pentwater	IR (Macrolite) with ID	Kinetico	400	13 ^(a)	466 ^(d)	6.9
Sandusky, MI	City of Sandusky	IR (Aeralater)	Siemens	340 ^(e)	16 ^(a)	1,387 ^(d)	6.9
Delavan, WI	Vintage on the Ponds	IR (Macrolite)	Kinetico	40	20 ^(a)	1,499 ^(d)	7.5
Goshen, IN	Clinton Christian School	IR & AM (E33)	AdEdge	25	29 ^(a)	810 ^(d)	7.4
Fountain City, IN	Northeastern Elementary School	IR (G2)	US Water	60	27 ^(a)	1,547 ^(d)	7.5
Waynesville, IL	Village of Waynesville	IR (Greensand Plus)	Peerless	96	32 ^(a)	2,543 ^(d)	7.1
Geneseo Hills, IL	Geneseo Hills Subdivision	AM (E33)	AdEdge	200	25 ^(a)	248 ^(d)	7.4
Greenville, WI	Town of Greenville	IR (Macrolite)	Kinetico	375	17 ^(a)	7,827 ^(d)	7.3
Climax, MN	City of Climax	IR (Macrolite) with ID	Kinetico	140	39 ^(a)	546 ^(d)	7.4
Sabin, MN	City of Sabin	IR (Macrolite)	Kinetico	250	34 ^(a)	1,470 ^(d)	7.3
Sauk Centre, MN	Big Sauk Lake Mobile Home Park	IR (Macrolite)	Kinetico	20	25 ^(a)	3,078 ^(d)	7.1
Stewart, MN	City of Stewart	IR &AM (E33)	AdEdge	250	42 ^(a)	1,344 ^(d)	7.7
Lidgerwood, ND	City of Lidgerwood	Process Modification	Kinetico	250	146 ^(a)	1,325 ^(d)	7.2
Lead, SD	Terry Trojan Water District	AM (ArsenX ^{np})	SolmeteX	75	24	<25	7.3
Midwest/Southwest							
Willard, UT	Hot Springs Mobile Home Park	IR & AM (Adsorbsia)	Filter Tech	30	15.4 ^(a)	332 ^(d)	7.5
Arnaudville, LA	United Water Systems	IR (Macrolite)	Kinetico	770 ^(e)	35 ^(a)	2,068 ^(d)	7.0
Alvin, TX	Oak Manor Municipal Utility District	AM (E33)	STS	150	19 ^(a)	95	7.8
Bruni, TX	Webb Consolidated Independent School District	AM (E33)	AdEdge	40	56 ^(a)	<25	8.0

**Table 1-1. Summary of Rounds 1, 2, and 2a Arsenic Removal Demonstration
Locations, Technologies, and Source Water Quality (Continued)**

Demonstration Location	Site Name	Technology (Media)	Vendor	Design Flowrate (gpm)	Source Water Quality		
					As (µg/L)	Fe (µg/L)	pH (S.U.)
Wellman, TX	City of Wellman	AM (E33)	AdEdge	100	45	<25	7.7
Anthony, NM	Desert Sands Mutual Domestic Water Consumers Association	AM (E33)	STS	320	23 ^(a)	39	7.7
Nambe Pueblo, NM	Nambe Pueblo Tribe	AM (E33)	AdEdge	145	33	<25	8.5
Taos, NM	Town of Taos	AM (E33)	STS	450	14	59	9.5
Rimrock, AZ	Arizona Water Company	AM (E33)	AdEdge	90 ^(b)	50	170	7.2
Tohono O'odham Nation, AZ	Tohono O'odham Utility Authority	AM (E33)	AdEdge	50	32	<25	8.2
Valley Vista, AZ	Arizona Water Company	AM (AAFS50/ARM 200)	Kinetico	37	41	<25	7.8
Far West							
Three Forks, MT	City of Three Forks	C/F (Macrolite)	Kinetico	250	64	<25	7.5
Fruitland, ID	City of Fruitland	IX (A300E)	Kinetico	250	44	<25	7.4
Homedale, ID	Sunset Ranch Development	POU RO ^(c)	Kinetico	75 gpd	52	134	7.5
Okanogan, WA	City of Okanogan	C/F (Electromedia-I)	Filtronics	750	18	69 ^(d)	8.0
Klamath Falls, OR	Oregon Institute of Technology	POE AM (Adsorbsia/ARM 200/ArsenX ^{np}) and POU AM (ARM 200) ^(g)	Kinetico	60/60/30	33	<25	7.9
Vale, OR	City of Vale	IX (Arsenex II)	Kinetico	525	17	<25	7.5
Reno, NV	South Truckee Meadows General Improvement District	AM (GFH)	Siemens	350	39	<25	7.4
Susanville, CA	Richmond School District	AM (A/I Complex)	ATS	12	37 ^(a)	125	7.5
Lake Isabella, CA	Upper Bodfish Well CH2-A	AM (HIX)	VEETech	50	35	125	7.5
Tehachapi, CA	Golden Hills Community Service District	AM (Isolux)	MEI	150	15	<25	6.9

AM = adsorptive media process; C/F = coagulation/filtration; HIX = hybrid ion exchanger; IR = iron removal; IR with ID = iron removal with iron addition; IX = ion exchange process; RO = reverse osmosis

ATS = Aquatic Treatment Systems; MEI = Magnesium Elektron, Inc.; STS = Severn Trent Services

(a) Arsenic existing mostly as As(III).

(b) Design flowrate reduced by 50% due to system reconfiguration from parallel to series operation.

(c) Selected originally to replace Village of Lyman, NE site, which withdrew from program in June 2006. Withdrew from program in 2007 and replaced by a home system in Lewisburg, OH.

(d) Iron existing mostly as Fe(II).

(e) Facilities upgraded systems in Springfield, OH from 150 to 250 gpm, Sandusky, MI from 210 to 340 gpm, and Arnaudville, LA from 385 to 770 gpm.

(f) Including nine residential units.

(g) Including eight under-the-sink units.

Table 1-2. Number of Demonstration Sites Under Each Arsenic Removal Technology

Technologies	Number of Sites
Adsorptive Media ^(a)	26
Adsorptive Media with Iron Removal Pretreatment	4
Iron Removal (Oxidation/Filtration)	8
Iron Removal with Supplemental Iron Addition	4
Coagulation/Filtration	3
Ion Exchange	2
Reverse Osmosis	1
Point-of-use Reverse Osmosis ^(b)	1
System/Process Modifications	1

(a) OIT site at Klamath Falls, OR, had three AM systems and eight POU AM units.

(b) Including nine under-the-sink RO units.

2.0 SUMMARY AND CONCLUSIONS

The Peerless C/F system using GreensandPlus™ media with an anthracite cap has been operational at the Village of Waynesville, IL since July 15, 2009. Based on the information collected during the demonstration period from system startup through September 19, 2010, the following conclusions were made relating to the overall objectives of the treatment technology demonstration study.

Performance of the arsenic removal technology for use on small systems:

- NaMnO₄ was effective in oxidizing As(III), reducing its concentrations from 24.1 µg/L (in source water) to 0.6 µg/L after oxidation. NaMnO₄ was selected over chlorine as an oxidant because of the presence of elevated total organic carbon (TOC) (7.9 mg/L [on average]) and ammonia (3.8 mg/L [as N]) in source water.
- NaMnO₄ was effective in oxidizing soluble iron, reducing its concentrations from 2,277 µg/L (in source water) to 48.1 µg/L after oxidation. Incomplete oxidation, however, was observed during three out of 13 speciation sampling events, leaving as much as 147 µg/L of soluble iron in NaMnO₄-treated water. The exact cause of the incomplete oxidation was not clear, but the elevated TOC and/or the formation of colloidal particles might contribute to the presence of “soluble” iron after NaMnO₄ addition.
- At an average NaMnO₄ dosage of 6.3 mg/L and a soluble iron to soluble arsenic ratio of 72:1, soluble As(III) was effectively converted to particulate arsenic, leaving only a small amount of soluble arsenic (i.e., 3.5 µg/L [on average]) in NaMnO₄-treated water. At a filtration rate of <3.4 gpm/ft², arsenic-laden iron particles were effectively removed by the GreensandPlus™ filters, leaving only 0.5 µg/L of particulate arsenic in the filter effluent. Soluble arsenic concentrations in the combined effluent also were low, averaging 3.3 µg/L.
- The presence of dissolved organic matter (DOM) in source water might have hindered the formation of filterable MnO₂ particles upon NaMnO₄ addition, causing the presence of a large amount of “soluble” manganese (i.e., 765 µg/L [on average]) in NaMnO₄-treated water. The “soluble” manganese was subsequently removed by the GreensandPlus™ filters via either filtration or chemical reaction with MnO₂ coatings on the media surface. Additional contact time might help form filterable particles prior to the media beds, as reflected by the significantly reduced manganese concentrations (<100 µg/L [on average]) in the filter effluent.
- It was essential to maintain a reducing condition throughout the treatment train so that soluble iron in raw water could be fully utilized to form arsenic-laden particles and that microbial activities, including nitrification, could be under control.
- Backwashing once every three days was effective in restoring the filters, allowing them to perform in a sustainable manner for arsenic and iron removal. Higher than secondary maximum contaminant level (SMCL) of manganese was measured in the filter effluent, with most existing in the particulate form.
- The water quality in the distribution system was improved after startup of the C/F treatment system. Arsenic and iron concentrations were significantly reduced, but remained higher than those in the filter effluent, suggesting solubilization, destabilization, and/or desorption of arsenic-laden particles/scales in some segments of the distribution system.
- Nitrification did not occur in the distribution system.

- Lead concentrations in the distribution system remained unchanged after system startup. Copper concentrations were reduced from the baseline level of 685 to 472 µg/L (on average) after system startup.

Required system O&M and operator skill levels:

- The daily demand on the operator was about 20 min. The work performed included routine O&M, such as tracking chemical levels in pre- and post-treatment day tanks; replenishing day tanks, if needed; and working with the equipment vendor and CMT Engineering (the Village's engineer) to troubleshoot and perform minor onsite repairs.
- Except for a few operational issues, the system did not experience any downtime throughout the demonstration study period.

Process residuals produced by the technology:

- During the first year of system operation, the system was backwashed 123 times, generating, on average, 3,100 gal of wastewater per backwash event. Upon adjustments on backwash/fast rinse duration and fast rinse flowrate, the system was backwashed 21 times, generating, on average, 4,226 gal of wastewater per backwash event. The total amount of wastewater produced was 470,000 gal, equivalent to 3.7% of the water production during the entire study period.
- Approximately 3,100 gal of wastewater was produced from each backwash event. It was estimated that approximately 11.4 lb of solids were discharged into the sewer during each backwash event. The solids contained 0.01 lb (or 5.0 g) of arsenic, 2.2 lb (or 1,014 g) of iron, and 1.2 lb (or 547 g) of manganese.

Capital and O&M cost of the technology:

- The total capital investment for the treatment system was \$161,559, including \$90,749 (or 56.2%) for equipment, \$22,460 (or 13.9%) for site engineering, and \$48,350 (or 29.9%) for system installation, shakedown, and startup.
- The normalized unit capital cost was \$1,683/gpm (or \$1.17 gal/day [gpd]) based on the system's rated capacity of 96 gpm.
- The total O&M cost was \$0.68/1,000 gal of treated water, including incremental costs for NaMnO₄, electricity, and labor.

3.0 MATERIALS AND METHODS

3.1 General Project Approach

Following pre-demonstration activities summarized in Table 3-1, the performance evaluation of the Peerless C/F system began on July 15, 2009, and ended on September 19, 2010. Table 3-2 summarizes the types of data collected and considered as part of the technology evaluation process. The overall system performance was evaluated based on its ability to consistently remove arsenic below the MCL of 10 µg/L through the collection of water samples across the treatment train, as described in the Study Plan (Battelle, 2009). The reliability of the system was evaluated by tracking unscheduled system downtimes and frequency and extent of repair and replacement. The plant operator recorded unscheduled downtimes and repair information on a Repair and Maintenance Log Sheet.

Table 3-1. Pre-demonstration Activities and Completion Dates

Activity	Date
Introductory Meeting	12/05/06
Letter Report Issued	01/23/07
Technology Selection Meeting	07/11/07
Technology Selection Teleconference	07/18/07
Trip to Michigan to Observe One Peerless System	08/15/07
Project Planning Meeting	10/02/07
Draft Letter of Understanding Issued	10/15/07
Final Letter of Understanding Issued	10/19/07
Request for Quotation Issued to Vendor	11/02/07
Initial Vendor Quotation Received by Battelle	12/05/07
Revised Vendor Quotation Received by Battelle	01/11/08
Construction Permit Issued by IL EPA	01/22/08
Final Vendor Quotation Received by Battelle	02/13/08
Purchase Order Completed and Signed	08/25/08
Building Construction Began	09/22/08
System Permit Package Submitted to IL EPA	10/23/08
System Permit Issued by IL EPA	01/09/09
Equipment Arrived at Site	02/17/09
Study Plan Issued	04/24/09
Building Construction Completed	04/30/09
System Installation Completed	05/08/09
System Shakedown Completed	06/15/09
Performance Evaluation Began	07/15/09

IL EPA = Illinois Environmental Protection Agency

The O&M and operator skill requirements were evaluated based on a combination of quantitative data and qualitative considerations, including the need for pre- and/or post-treatment, level of system automation, extent of preventative maintenance activities, frequency of chemical and/or media handling and inventory, and general knowledge needed for relevant chemical processes and related health and safety practices. The staffing requirements for the system operation were recorded on an Operator Labor Hour Log Sheet.

Table 3-2. Evaluation Objectives and Supporting Data Collection Activities

Evaluation Objectives	Data Collection
Performance	–Ability to consistently meet 10 µg/L of arsenic MCL in treated water
Reliability	–Unscheduled system downtime –Frequency and extent of repairs including a description of problems encountered, materials and supplies needed, and associated labor and cost incurred
System O&M and Operator Skill Requirements	–Pre- and post-treatment requirements –Level of automation for system operation and data collection –Staffing requirements including number of operators and laborers –Task analysis of preventative maintenance including number, frequency, and complexity of tasks –Chemical handling and inventory requirements –General knowledge needed for relevant chemical processes and health and safety practices
Residual Management	–Quantity and characteristics of aqueous and solid residuals generated by system operation
Cost-Effectiveness	–Capital cost for equipment, engineering, and installation –O&M cost for chemical usage, electricity consumption, and labor

The quantity of aqueous and solid residuals generated was estimated by tracking the volume of backwash wastewater produced during each backwash cycle. Backwash water and solids were sampled and analyzed for chemical characteristics.

The system cost was evaluated based on the capital cost per gpm (or gpd) of design capacity and the O&M cost per 1,000 gal of water treated. This required tracking the capital cost for equipment, site engineering, and installation, as well as the O&M cost for chemical supply, electrical usage, and labor.

3.2 System O&M and Cost Data Collection

The plant operator performed daily, biweekly, and monthly system O&M and data collection according to instructions provided by the vendor and Battelle. On a regular basis, the plant operator recorded system operational data such as hour meter, flowrate, totalizer, and pressure readings on a System Operation Log Sheet and conducted visual inspections to ensure normal system operations. If any problems occurred, the plant operator contacted the Battelle Study Lead, who determined if the vendor should be contacted for troubleshooting. The plant operator recorded all relevant information, including the problems encountered, course of actions taken, materials and supplies used, and associated cost and labor incurred on the Repair and Maintenance Log Sheet. The operator of the Geneseo Hills Subdivision water system traveled to Waynesville, IL monthly to conduct arsenic speciation and measure pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP) and recorded the data on an Onsite Water Quality Parameters Log Sheet.

The capital cost for the arsenic treatment system consisted of the cost for equipment, site engineering, and system installation. The O&M cost consisted of the cost of chemical supply, electricity consumption, and labor. Labor for various activities, such as the routine system O&M, troubleshooting and repairs, and demonstration-related work, were tracked using an Operator Labor Hour Log Sheet. The routine system O&M included activities such as completing field logs, ordering supplies, performing system inspections, and others as recommended by the vendor. The labor for demonstration-related work, including activities such as collecting field measurements, collecting and shipping samples, and communicating with the Battelle Study Lead and the vendor, was recorded, but not used for cost analysis.

3.3 Sample Collection Procedures and Schedules

To evaluate system performance, samples were collected from the wellhead, across the treatment plant, during backwash of the filtration tanks, and from the distribution system. Table 3-3 presents sampling schedules and analytes measured during each sampling event. Specific sampling requirements for analytical methods, sample volumes, containers, preservation, and holding times are presented in Table 4-1 of the EPA-endorsed Quality Assurance Project Plan (QAPP) (Battelle, 2007). The procedure for arsenic speciation is described in Appendix A of the QAPP.

3.3.1 Source Water. During the initial site visit on December 5, 2006, two sets of source water samples were collected from Wells No. 6 and No. 8 and speciated using an arsenic speciation kit (see Section 3.5.1). The sample tap was flushed for several minutes before sampling; special care was taken to avoid agitation, which might cause unwanted oxidation. Analytes for the source water samples are listed in Table 3-3.

3.3.2 Treatment Plant Water. The Battelle Study Plan (Battelle, 2009) called for sampling of treatment plant water once every two weeks, with “speciation sampling” performed during the first week of each four-week cycle and “regular sampling” performed during the third week of each four-week cycle. Regular sampling involved collecting water samples at the wellhead (IN), after oxidation (AO), and after Vessels A, B, C, and D (TA, TB, TC, and TD) and having them analyzed for the analytes listed under “regular sampling” in Table 3-3. Speciation sampling involved collecting and speciating samples at IN, AO, and after effluent from the four filtration vessels combined (TT) and having them analyzed for the analytes listed under speciation sampling in Table 3-3.

Except for the last three sampling events where only monthly speciation sampling was conducted, speciation and regular sampling alternated every two weeks, as planned, during most of the rest of the study period. Sampling intervals were adjusted to one to four weeks occasionally to accommodate holidays and operator schedules.

3.3.3 Backwash Wastewater and Solids. The operator collected backwash wastewater samples from each of the four filtration vessels on 12 occasions. Over the duration of each backwashing event, a side stream of backwash wastewater was directed from the tap on the backwash water discharge line to one of four clean, 32-gal plastic containers at approximately 1 gpm. After the contents in each container were thoroughly mixed, one aliquot was collected as is for total As, Fe, and Mn, pH, total dissolved solids (TDS), and total suspended solids (TSS) analysis and the other aliquot filtered with 0.45- μ m disc filters for soluble As, Fe, and Mn analysis.

Once during the performance evaluation study, the contents in a 32-gal plastic container were allowed to settle and the supernatant was carefully siphoned using a piece of plastic tubing to avoid agitating settled solids in the container. The remaining solids/water mixture was then transferred to a 1-gal plastic jar. After solids in the jar were settled and the supernatant was carefully decanted, one aliquot of the solids/water mixture was air-dried before being acid-digested and analyzed for the metals listed in Table 3-3.

3.3.4 Distribution System Water. Water samples were collected from the distribution system to determine the impact of the arsenic treatment system on the water chemistry in the distribution system, specifically, the arsenic, lead, and copper levels. Prior to system startup from March 9 through May 13, 2009, six sets of baseline samples were collected from three residences within the Village’s Lead and Copper Rule (LCR) sampling network. Following system startup, distribution system water sampling continued on a monthly basis at the same three locations until September 15, 2010.

Table 3-3. Sampling Schedule and Analytes

Sample Type	Sample Locations^(a)	No. of Samples	Frequency	Analytes	Sampling Date
Source Water	Well No. 6 and Well No. 8	2	Once (During initial site visit)	Onsite: pH, temperature, DO, and ORP Offsite: As (III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Sb (total and soluble), V, Na, Ca, Mg, Cl, F, NO ₃ , NO ₂ , NH ₃ , SO ₄ , SiO ₂ , PO ₄ , P, turbidity, alkalinity, TDS, and TOC	12/05/06
Treatment Plant Water (Speciation)	IN, AO, and TT ^(b)	3	Monthly ^(c)	Onsite: pH, temperature, DO, and ORP Offsite: As(III), As(V), As (total and soluble), Fe (total and soluble), Mn (total and soluble), Ca, Mg, F, NO ₃ , NH ₃ , SO ₄ , SiO ₂ , P, turbidity, alkalinity, and TOC	See Appendix B
Treatment Plant Water (Regular)	IN, AO, TA, TB, TC, and TD	6	Monthly ^(c)	Onsite: none Offsite: As (total), Fe (total), Mn (total), NH ₃ , SiO ₂ , P, turbidity, and alkalinity	See Appendix B
Distribution System Water	Three LCR Residences (DS)	3	Monthly	As (total), Fe (total), Mn (total), Cu, Pb, NO ₃ , NO ₂ , NH ₃ , pH, alkalinity, and TOC ^(d)	See Table 4-16 ^(e)
Backwash Water	Backwash Discharge Line (BW)	4	Monthly	As (total and soluble), Fe (total and soluble), Mn (total and soluble), pH, TDS, and TSS	See Table 4-14
Backwash Solids	Wastewater Container from Each Vessel	4	Once	Al, As, Ba, Ca, Cd, Cu, Fe, Mg, Mn, Ni, P, Pb, Si, and Zn	07/15/09

(a) Abbreviations in parenthesis corresponding to sample locations shown in Figure 4-4, i.e., IN = at wellhead; AO = after oxidation; TA/TB/TC/TD = after Vessels A/B/C/D; TT = combined effluent from Vessels A, B, C, and D; BW = backwash discharge line; DS = distribution system.

(b) TT samples collected at TA during four speciation sampling events on 04/22/10, 05/19/10, 08/18/10, and 09/15/10.

(c) Alternating between speciation and regular sampling events.

(d) Ammonia, nitrate, and TOC analyses began on 05/06/09; nitrite analysis began on 12/02/09.

(e) Including six baseline sampling events before system startup.

DO = dissolved oxygen; ORP = oxidation-reduction potential; TDS = total dissolved solids; TOC = total organic carbon; TSS = total suspended solids

The operator collected the samples following an instruction sheet developed in accordance with the *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems* (EPA, 2002). The date and time of last water usage before sample collection were recorded for calculating stagnation time. All samples were collected from a cold-water faucet that had not been used for at least six hours to ensure that stagnant water was collected for analysis.

3.4 Oxidant Demand and Disinfection Byproducts Formation Potential Studies

Due to the reducing nature of raw water at Waynesville, IL, chemical oxidation with either sodium hypochlorite (NaOCl) or sodium permanganate (NaMnO₄) was necessary for effective arsenic removal by the proposed treatment system. NaOCl can oxidize reduced metals, including soluble As(III) and soluble Fe(II), and provide residuals in finished water. However, NaOCl may react with TOC to form disinfection byproducts (DBPs), especially at greatly elevated levels. NaOCl also will react with ammonia to form combined chlorine, which is ineffective in oxidizing both soluble As(III) and soluble Fe(II). NaMnO₄ can be used as an alternative oxidant. It can oxidize reduced metals, including soluble As(III), and does not form DBPs even in the presence of elevated TOC. The use of NaMnO₄ will form MnO₂, which can be present as colloidal particles not filterable by the GreensandPlus™ filters. Further, it is often difficult to regulate NaMnO₄ dosage due to factors such as changing water quality. Over dosing will result in pink water.

Because ammonia and TOC also were present at elevated levels (i.e., >3.6 mg/L [as N] and 9.0 mg/L [as C], respectively [see Table 4-1]), it was important to select an oxidant and a dose that would not only oxidize soluble As(III) and soluble Fe(II) for their effective removal, but also not cause unwanted formation of DBPs due to its use. Thus, the goals of this special study were:

1. To determine an appropriate oxidant and its dose to effectively oxidize soluble As(III), soluble Fe(II), and other reducing species.
2. To determine DBP formation potential through the application of each oxidant at a specific dose.

To accomplish these goals, a series of jar tests was conducted onsite based on a method modified from the uniform formation conditions (UFC) test developed by Summers et al. (1996) for DBP formation in drinking water. The following subsections describe the method used to collect representative raw water samples and the specific procedures developed for the jar tests.

3.4.1 Raw Water Sample Collection. Raw water was collected from the Well No. 8 sample tap (see the well information in Section 4.1) in a way to reduce oxidation of the source water and preserve its in-well characteristics throughout the jar tests. A 2-ft piece of Tygon® tubing was first connected to the tip of the sample tap to produce a laminar flow. The tap and the tubing were then thoroughly flushed with Well No. 8 water for approximately 20 min. To ensure no incidental addition of any chemical at the wellhead, all three chemical addition pumps that dispensed sodium hypochlorite (NaOCl), hydrofluorosilic acid (H₂SiF₆), and polyphosphate were turned off. After the flow through the Tygon® tubing was restored to a laminar flow, the end of the tubing was placed to the bottom of a 2.5-gal clear plastic jug to fill the jug. Once the jug was filled, it was allowed to overflow to remove the layer of potentially oxidized water. In doing so, potential oxidation of the raw water would be diffusion-limited to a small layer near the air/water interface within the jug and relatively far away from the sampling tap located near the bottom of the jug.

In addition to the tap near the bottom of the jug, the jug also was equipped with a small opening (and a screw-on cap) on its top to provide pressure during water dispensing. When the tap was not used, the cap

was screwed on tightly to reduce air intrusion. The water just below the interface was periodically observed during the experiment for signs of oxidation (light attenuation and scattering caused by precipitation of oxidized metals). No sign of significant oxidation was noted during the study, although a slight yellow hue was observed in the jug approximately 60 min after sampling. Water with an appreciably noticeable yellow hue was not used for the jar tests.

3.4.2 Oxidant Demand Studies. One L of a NaOCl stock solution was prepared by diluting 10 mL of a ~10% NaOCl solution with Milli-Q deionized (DI) water. To validate the stock solution concentration (i.e., ~1 g/L [as Cl₂]), free chlorine measurements were made on a 1:1,000 diluted solution using Hach colorimetric test kits (Method 8167). KMnO₄ was used as a surrogate for NaMnO₄ in this study. One L of a KMnO₄ stock solution was prepared by dissolving an appropriate mass of crystalline KMnO₄ for a final concentration of 1.0 g/L (as KMnO₄). MnO₄⁻ concentrations of a 1:1,000 diluted solution were measured onsite using a Hach DR/820 colorimeter via the N, N-diethyl-p-phenylenediamine (DPD) method (Carus Corporation, 2001) and verified by inductively coupled plasma-mass spectrometry (ICP-MS).

Oxidant demands of Well No. 8 water were determined by using the experimental matrix presented in Table 3-4. Aliquots of the two stock solutions were added into separate 1-L amber glass bottles (reaction bottles). The reaction bottles were then filled, with minimum agitation, with raw water from the 2.5-gal jug and capped with Teflon[®]-lined caps with no headspace. Actual doses of chlorine and manganese were verified with three reaction bottles each spiked with a known amount of an oxidant stock solution and filled with DI water. After 20 min of contact time, the Teflon[®]-lined cap of a chosen reaction bottle was removed and a 10-mL sample was taken and analyzed for either total chlorine or MnO₄⁻. The reaction bottles were properly staggered to allow time for sampling and analysis.

Table 3-4. Oxidant Demand Study Experimental Matrix

Parameter/Condition	Unit	Values
Chlorine Dose	mg/L (as Cl ₂)	0.0, 2.6, 4.9, 7.0, 9.1, 12.8, 16.4
Permanganate Dose	mg/L (as KMnO ₄)	0.0, 6.0, 8.5, 11.5, 17.5
Reaction Time	min	20
Temperature	°C	Ambient

The 20-min contact time was chosen to mimic the longest time possible for the well water to travel from the wellhead (either Well No. 6 or No. 8) to the top of an anthracite/GreensandPlus[™] bed. Under normal operating conditions with both wells running at a combined flowrate of 19 gpm/vessel, the time for the well water to reach a filtration bed is less than 10 min.

3.4.3 Arsenic/Iron Removal and DBP Formation Potential Study. Once the oxidant demand of Well No. 8 water was determined, the effect of NaOCl and KMnO₄ on treated water quality, including DBP formation potential, was examined using a series of jar tests. For NaOCl, two doses at 8 and 10 mg/L (as Cl₂) were tested; for KMnO₄, only one dose at 6 mg/L (as KMnO₄) was tested. The 8 mg/L NaOCl and 6 mg/L KMnO₄ jars were allowed to contact for 20 min. The 10 mg/L NaOCl jar was allowed to contact for 120 min, an extended duration that mimicked an absolute worst-case scenario. Long residence times could contribute to higher DBP concentrations (Rathbun, 1997; Summers et al., 1996). As done for the oxidant demand jars, each oxidant was spiked with its separately determined dose to a 1-L reaction bottle before being filled with raw water from the 2.5-gal jug. After a prescribed contact time, the cap to a reaction bottle was removed and the contents in the bottle were taken for both onsite and offsite measurements/analyses. Table 3-5 presents the experimental matrix.

Table 3-5. Experimental Matrix for Arsenic/Iron Removal and DBP Formation Studies

Oxidant	Oxidant Dose (mg/L)	Reaction Time (min)	Total As, Fe, and Mn	Soluble As, Fe, and Mn	Soluble As (III)	Soluble As (V)	Ammonia	TOC	TTHM	HAA5	pH	Temperature	DO	ORP	Total Chlorine	KMnO ₄
None	NA	0	×	×	×	×	×	×			×	×	×	×		
NaOCl	8.0	20	×	×	×	×	×	×	×	×	×	×	×	×	×	
NaOCl	10.0	120	×	×	×	×	×	×	×	×	×	×	×	×	×	
KMnO ₄	6.0	20	×	×	×	×	×	×	×	×	×	×	×	×		×

To ensure proper sampling and analyses, two persons sampled each reaction bottle as quickly as possible in the order listed below:

- A 40 mL sample was extracted from the reaction bottle with a plastic syringe and filtered through a 0.45 µm disc filter to a 40 mL volatile organic analysis (VOA) vial containing 1 mL of 0.1 N Na₂S₂O₃ for total trihalomethanes (TTHM) analysis. The bottle was filled with no headspace. This step was performed in duplicate for laboratory quality assurance/quality control (QA/QC).
- A second sample was extracted from the reaction bottle using a second plastic syringe and filtered through a 0.45 µm disc filter to a 100 mL VOA vial containing 0.1 mL of 70% (v/v) H₂SO₄ for TOC analysis. The bottle was filled with no headspace.
- Immediately after the TOC VOA vial had been filled, onsite arsenic speciation began.
- During the arsenic speciation, 50 mL of 0.45 µm disc filtered water from the reaction bottle was added to a 50 mL certified pre-cleaned high-density polyethylene (HDPE) sample bottle containing H₂SO₄ (to pH < 2) for NH₃ analysis.
- Subsequently, a 60 mL amber glass sample bottle containing 2 mL of 10% Na₂S₂O₃ was filled with unfiltered water from the reaction bottle for haloacetic acids (HAA5) analysis. The bottle was filled with no headspace. This step was performed in triplicate for laboratory QA/QC.
- Total chlorine or permanganate (as measured by a handheld Hach colorimeter), pH, ORP and temperature (as measured by a portable VWR SP90M5 meter) were measured last.

3.5 Sampling Logistics

3.5.1 Preparation of Arsenic Speciation Kits. The arsenic field speciation method used an anion exchange resin column to separate the soluble arsenic species, As(V) and As(III) (Edwards et al., 1998). Resin columns were prepared in batches at Battelle laboratories in accordance with the procedures detailed in Appendix A of the EPA-endorsed QAPP (Battelle, 2007).

3.5.2 Preparation of Sampling Coolers. For each sampling event, a sample cooler was prepared with the appropriate number and type of sample bottles, disc filters, and/or speciation kits. All sample bottles were new and contained appropriate preservatives. Each sample bottle was affixed with a pre-printed, color-coded label consisting of sample identification (ID), date and time of sample collection, collector's name, site location, sample destination, analysis required, and preservative. The sample ID consisted of a two-letter code for a specific water facility, sampling date, a two-letter code for a specific sampling location, and a one-letter code designating the arsenic speciation bottle (if necessary). The sampling locations at the treatment plant were color-coded for easy identification. The labeled bottles for each sampling location were placed in separate zip-lock bags and packed in the cooler.

In addition, all sampling- and shipping-related materials, such as disposable gloves, sampling instructions, chain-of-custody forms, prepaid/addressed FedEx air bills, and bubble wrap, were included in the cooler. The chain-of-custody forms and air bills were complete except for the operator's signature and the sample dates and times. After preparation, the sample cooler was sent to the site via FedEx for the following week's sampling event.

3.5.3 Sample Shipping and Handling. After sample collection, samples for offsite analyses were packed carefully in the original coolers with wet ice and shipped to Battelle. Upon receipt, the sample custodian verified that all samples indicated on the chain-of-custody forms were included and intact. Sample IDs were checked against the chain-of-custody forms, and the samples were logged into the laboratory sample receipt log. Discrepancies noted by the sample custodian were addressed with the operator by the Battelle Study Lead.

Samples for metals analyses were stored at Battelle's ICP-MS laboratory. Samples for other water analyses were packed in separate coolers and picked up by couriers from American Analytical Laboratories (AAL) in Columbus, OH and Belmont Labs in Englewood, OH, both of which were under contract with Battelle for this demonstration study. The chain-of-custody forms remained with the samples from the time of preparation through analysis and final disposition. All samples were archived by the appropriate laboratories for the respective duration of the required hold time and disposed of properly thereafter.

3.6 Analytical Procedures

The analytical procedures described in detail in Section 4.0 of the EPA-endorsed QAPP (Battelle, 2007) were followed by Battelle's ICP-MS laboratory, AAL, and Belmont Labs. Laboratory QA/QC of all methods followed the prescribed guidelines. Data quality in terms of precision, accuracy, method detection limits (MDL), and completeness met the criteria established in the QAPP (i.e., relative percent difference [RPD] of 20%, percent recovery of 80 to 120%, and completeness of 80%). The QA data associated with each analyte will be presented and evaluated in a QA/QC Summary Report to be prepared under separate cover upon completion of the Arsenic Demonstration Project.

Field measurements of pH, temperature, DO, and ORP were conducted by the operator using a VWR Symphony SP90M5 Handheld Multimeter, which was calibrated for pH and DO prior to use in accordance with the procedures provided in the user's manual. The ORP probe also was checked for accuracy by measuring the ORP of a standard solution and comparing it to the expected value. The operator collected a water sample in a clean, plastic beaker and placed the Symphony SP90M5 probe in the beaker until a field measurement was stable and recorded on the log sheet.

4.0 RESULTS AND DISCUSSION

4.1 Pre-existing Facility Description and Treatment System Infrastructure

The Village of Waynesville water treatment facility is a community water system (CWS) serving approximately 452 residents. The system is supplied by two wells, i.e., Wells No. 6 and 8, typically operating 3 to 5 and 8 to 10 hr/day, respectively, to meet the Village's average daily demand of approximately 29,000 gal. Well No. 6 is 6-in in diameter and 156 ft deep with a static water level at approximately 94 ft below ground surface (bgs). The well is equipped with a 7.5-horsepower (hp) submersible pump rated for 36 gpm at 96.9 ft water (H_2O) of total dynamic head (TDH) or 42 lb/in² (psi). Well No. 8 is 10-in in diameter and 206 ft deep with a static water level at approximately 110 ft bgs. The well is equipped with a 5-hp submersible pump rated for 42 gpm at 124.6 ft H_2O of TDH or 54 psi. The two wells and respective pump houses are located approximately 600 ft apart. There is an additional well at the Village, Well No. 7 (adjacent to Well No. 8); however, this well is not operational and is only used during an emergency.

Located next to the Village Hall at 200 E. Second Street, the Well No. 6 pump house is a 24 ft × 14 ft × 8 ft structure, which houses the wellhead piping, three chemical addition systems, one 2-in totalizer, and pressure gauges (see Figure 4-1). The pre-existing treatment included chlorination, fluoridation, and polyphosphate addition. Chlorination was accomplished using a 12.5% NaOCl solution to maintain a target dosage of 3.0 mg/L (as Cl_2). Target free and total chlorine residuals as required by the state were 0.2 and 0.5 mg/L (as Cl_2), respectively. The chlorination system consisted of a 50-gal polyethylene chemical day tank and a 22-gpd Premier flow-paced metering pump with the speed and stroke set at 65% and 90%, respectively. Fluoridation was carried out using a 23% hydrofluorosilic acid (H_2SiF_6) for a target fluoride dosage of 0.9 to 1.2 mg/L. The system consisted of a 15-gal drum and a 3-gpd Stenner Peristaltic pump. Polyphosphate was added using a 34.5% phosphate solution to maintain a target dosage of 3.0 mg/L (as PO_4) for iron sequestration. The polyphosphate addition system consisted of a 50-gal polyethylene chemical day tank and a 22-gpd Premier flow-paced metering pump. The chemical pumps are interlocked with the Well No. 6 pump.

Adjacent to the water tower, the Well No. 8 pump house is a 20 ft × 8 ft × 8 ft structure, which provides shelter to the wellhead piping, three chemical addition systems, one 2-in totalizer, and pressure gauges (see Figure 4-2). Similar to those for Well No. 6, the chemical addition systems maintained the same target levels of chlorine, fluoride, and polyphosphate and were turned on simultaneously with the Well No. 8 pump.

Both well pumps are controlled automatically by level sensors in the 100 ft-tall, 50,000-gal water tower (Figure 4-3) with the high level sensor (i.e., pumps off) set at 83.88 ft or 36.36 psi and the low level sensor (i.e., pumps on) set at 81.90 ft or 35.50 psi. The tank overflow line is at 84.14 ft or 36.47 psi.

4.1.1 Source Water Quality. Source water samples were collected from both wells on December 5, 2006, when a Battelle staff member traveled with EPA to the site to attend an introductory meeting for this demonstration project. Samples from Well No. 6 water were speciated and analyzed both onsite and offsite for a complete set of analytes presented in Table 4-1. Samples from Well No. 8 water also were speciated, but analyzed for only a few select analytes shown in Table 4-1.

Analytical results from the December 5, 2006, sampling event are presented in Table 4-1 and compared to source water quality data provided by EPA for site selection and historic data collected from January 7, 2003, through December 11, 2006, by IL EPA. In general, the Battelle data are comparable to and within the range of those provided by EPA and IL EPA.



Figure 4-1. Well No. 6 Pump House and Pre-existing Chemical Addition Systems



Figure 4-2. Well No. 8 Pump House and Piping



Figure 4-3. 50,000-gal Water Tower

Arsenic. Total arsenic concentrations in source water ranged from 9.6 to 34.0 $\mu\text{g/L}$ for Well No. 6 and 16.0 to 40.0 $\mu\text{g/L}$ for Well No. 8. Based on the December 5, 2006, speciation results, out of 28.3 and 34.6 $\mu\text{g/L}$ of total arsenic, 62% and 80% of total arsenic, respectively, existed as soluble As(III), indicating that water from both wells was reducing. This observation was supported by the low DO (1.1 to 1.4 mg/L) and ORP (-14 to 4.4 mV) readings measured onsite at Wells No. 6 and No. 8. Soluble As(III) must be oxidized using chlorine or an alternative oxidant for more effective removal by C/F. No prior information on arsenic speciation was available for source water from either Wells No. 6 or No. 8.

Iron and Manganese. When selecting a C/F or IR process for arsenic removal, soluble iron concentration should be at least 20 times the soluble arsenic concentration to achieve effective treatment results (Sorg, 2002). Based on the historical data provided by IL EPA, total iron concentrations in source water were 340 and 3,100 $\mu\text{g/L}$ for Wells No. 6 and 8, respectively, which exceed the 300- $\mu\text{g/L}$ SMCL for iron. The relatively low iron concentration in Well No. 6 water might not be representative of actual water quality since the total iron concentration measured on July 5, 2002, was 2,900 $\mu\text{g/L}$, which is closer to the anticipated level and comparable to that measured in Well No. 8 water.

Table 4-1. Village of Waynesville Water Quality Data

Parameter	Unit	EPA Data 03/07/06		Battelle Data 12/05/06		IL EPA Historical Data 01/07/03–12/11/06	
		Well No. 6	Well No. 8	Well No. 6	Well No. 8	Well No. 6	Well No. 8
pH	S.U.	NA	NA	7.0	7.2	NA	NA
Temperature	°C	NA	NA	14.0	13.6	NA	NA
DO	mg/L	NA	NA	1.1	1.4	NA	NA
ORP	mV	NA	NA	-14	4.4	NA	NA
Total Alkalinity (as CaCO ₃)	mg/L	NA	NA	681	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	445	440	481	467	NA	NA
Turbidity	NTU	NA	NA	35	NA	NA	NA
TDS	mg/L	NA	NA	338	NA	NA	NA
TOC	mg/L	NA	NA	9.0	NA	NA	NA
Nitrate (as N)	mg/L	<0.02	<0.02	<0.05	NA	<0.1–0.1	<0.1
Nitrite (as N)	mg/L	<0.01	<0.01	<0.05	NA	<0.1	<0.1
Ammonia (as N)	mg/L	4.0	3.8	3.6	NA	NA	NA
Chloride	mg/L	NA	NA	7	NA	NA	NA
Fluoride	mg/L	NA	NA	0.9	NA	0.4–1.5	0.4–1.5
Sulfate	mg/L	0.4	0.3	<1	NA	<10	<10
Silica (as SiO ₂)	mg/L	20.2	19.1	20.1	NA	NA	NA
Orthophosphate (as PO ₄)	mg/L	0.02	0.04	NA	NA	NA	NA
Phosphorus (as PO ₄)	mg/L	0.2	0.3	0.3	0.04	NA	NA
Al (total)	µg/L	<25	<25	NA	NA	NA	NA
As (total)	µg/L	14	31	28.3	34.6	9.6–34.0	16.0–40.0
As (soluble)	µg/L	NA	NA	21.2	30.4	NA	NA
As (particulate)	µg/L	NA	NA	7.1	4.2	NA	NA
As(III)	µg/L	NA	NA	17.4	27.7	NA	NA
As(V)	µg/L	NA	NA	3.8	2.7	NA	NA
Fe (total)	µg/L	2,440	2,429	2,659	2,427	340 ^(a)	3,100
Fe (soluble)	µg/L	NA	NA	2,350	562	NA	NA
Mn (total)	µg/L	16.3	19.9	18.9	21.0	16	22
Mn (soluble)	µg/L	NA	NA	18.4	19.6	NA	NA
Sb (total)	µg/L	<25	<25	<0.1	<0.1	<2	<2
Sb (soluble)	µg/L	NA	NA	<0.1	<0.1	NA	NA
V (total)	µg/L	NA	NA	0.3	0.1	NA	NA
Na (total)	mg/L	51.8	41.6	59.3	49.1	63	54
Ca (total)	mg/L	96.1	93.4	103	98.2	NA	NA
Mg (total)	mg/L	49.7	50.1	54.0	53.8	NA	NA

(a) Sample collected on July 5, 2002 indicated total iron concentration of 2,900 µg/L.

IL EPA = Illinois EPA; NA = not available; NTU = nephelometric turbidity unit TDS = total dissolved solids; TOC = total organic carbon

Based on the data collected on December 5, 2006, water from Wells No. 6 and No. 8 contained 2,659 and 2,427 µg/L of total iron, respectively, 88% and 23% of which existed in the soluble form. The presence of mostly particulate iron in Well No. 8 water was believed to be due to incidental aeration during sampling. Based on the Well No. 6 data, the soluble iron concentration was 110 times the soluble arsenic concentration. This soluble iron to soluble arsenic ratio was favorable to the planned C/F process utilizing indigenous iron for arsenic removal. EPA data indicate total iron concentrations of 2,440 and

2,429 µg/L in Wells No. 6 and No. 8 water, respectively, which are similar to Battelle's results (although EPA data do not include soluble iron concentrations).

Based on the December 5, 2006, data, total manganese concentrations for Wells No. 6 and 8 were 18.9 and 21.0 µg/L, respectively, existing almost entirely in the soluble form. Total manganese results collected by Battelle are consistent with those provided by both EPA and IL EPA. All manganese concentrations were below its SMCL of 50 µg/L.

Ammonia and TOC. Source water contained high levels of ammonia (3.6 to 4.0 mg/L [as N]) and high levels of TOC (9.0 mg/L [as C]). If chlorine is used as the oxidant, chlorine will react with ammonia to form mono- and di-chloramines (or combined chlorine) at a 5:1 chlorine (as Cl₂) to ammonia (as N) ratio. To reach the breakpoint chlorination, the ratio will increase to approximately 7.6:1. To achieve the state-required free chlorine residual level of 0.2 mg/L (as Cl₂), approximately 30.6 mg/L of chlorine (as Cl₂) would be needed to react with reduced metals (i.e., soluble As[III], Fe[II], and Mn[II]) and ammonia, specifically:

- 1.5 mg/L of chlorine (as Cl₂) to react with 17.4 µg/L of soluble As(III), 2,350 µg/L of soluble Fe(II), and 18.4 µg/L of soluble Mn(II) (see Table 4-1),
- 28.9 mg/L of chlorine (as Cl₂) to completely oxidize an average of 3.8 mg/L of ammonia (as N) at the breaking point, and
- 0.2 mg/L of chlorine (as Cl₂) to provide the required 0.2 mg/L of free chlorine residual.

The use of 30.6 mg/L of chlorine (as Cl₂) not only adds to the chemical cost, but also exceeds the maximum residual disinfectant level (MRDL) and maximum residual disinfectant level goal (MRDLG) of 4 mg/L (as Cl₂) as stipulated in the Stage 1 Disinfectants and Disinfection Byproducts Rule (EPA, 1998). Therefore, it would not be practical or regulatorily acceptable to apply breakpoint chlorination to the source water containing highly elevated ammonia. Less chlorine used would ensure formation of only combined chlorine, which is known to be less effective in oxidizing soluble As(III) (Chen et al., 2009b; Ghurye and Clifford, 2001) and even soluble Fe(II) (Chen et al., 2009b; Valigore et al., 2008; Vikesland and Valentine, 2002). Combined chlorine also is not effective in reacting with TOC to form DBPs (Bougeard et al., 2010; Amy et al., 1984).

Due to the fact that combined chlorine is a less effective oxidant, NaMnO₄ was proposed to be the oxidant. A series of jar tests was conducted onsite to verify the chemistry of combined chlorine (as discussed above) and determine optimal KMnO₄ dosage.

Although the use of KMnO₄ as an oxidant circumvents some of the issues associated with NaOCl, it too presents its own set of unique challenges, which can affect the quality of finished water. First, KMnO₄ in sufficient concentrations will impart a pink color to treated water; this color subsides as KMnO₄ is reduced to MnO₂. Another potential issue is an increase in manganese concentration in finished water. As MnO₄⁻ is reduced, it is transformed to solid MnO₂, which can be removed by the GreensandPlus™ filters at the expense of longer filter run lengths. Manganese dioxide, however, does not always precipitate in a size fraction that is readily filterable. Studies conducted by Battelle suggest that in the presence of elevated TOC, MnO₂ is primarily precipitated in the colloidal size fraction (Shiao et al., 2009), which is too small to be removed by filtration (Pellitier, 2010). (For the purposes of the current study, all particulates able to pass through 0.45-µm filters are considered part of the soluble fraction). Knocke et al. (1990) defines colloidal particles as those passing through 0.20-µm filters and requiring ultrafiltration for removal. In the Battelle study, it was found that increasing KMnO₄ dosage can promote the formation of larger MnO₂ particles, which are then able to be removed by traditional filtration.

Therefore, on the one hand, KMnO_4 dose must be kept minimal to avoid water coloration and elevated manganese in the finished water; on the other hand, KMnO_4 must be added in sufficient dose to oxidize soluble As(III) and soluble Fe(II) while still imparting sufficient oxidant to form filterable-size fractions of MnO_2 .

Competing Ions. Arsenic removal via iron removal potentially can be affected by the presence of silica and phosphorus in raw water. Silica concentrations ranged from 19.1 to 20.1 mg/L (as SiO_2). Silica can be removed by iron solids and iron-based AM, thus affecting arsenic removal (see the review in the final performance evaluation report for the LEADS Head Start Building demonstration project in Buckeye Lake, OH [Chen et al., 2011a]). Phosphorus concentrations ranged from 0.04 to 0.3 mg/L (as PO_4) with up to 0.04 mg/L (as PO_4) existing as orthophosphate. Significantly elevated phosphorus concentrations and its removal by iron solids also were observed at a number of arsenic demonstration sites, including Big Sauk Lake Mobile Home Park in Sauk Centre, MN (Shiao et al., 2009), Hot Springs Mobile Home Park in Willard, UT (Wang et al., 2011), City of Stewart in MN (Condit et al., 2009), and Town of Arnaudville, LA (Chen et al., 2011b). Therefore, the effects of silica and phosphorus on arsenic removal were closely monitored during the performance evaluation study.

Other Water Quality Parameters. Data collected by Battelle indicate a near neutral pH of 7.0 and 7.2 for Wells No. 6 and 8, respectively, which are well within the acceptable target range of 5.5 to 8.5 for arsenic removal. Total alkalinity concentration was 681 mg/L (as CaCO_3); total hardness concentrations ranged from 440 to 481 mg/L (as CaCO_3); turbidity level was 35 nephelometric turbidity unit (NTU); TDS level was 338 mg/L; vanadium ranged from 0.1 to 0.3 $\mu\text{g/L}$; sodium ranged from 41.6 to 63.0 mg/L; and sulfate ranged from > 1 to 0.4 mg/L. All other analytes were below detection limits and/or anticipated to be low enough not to adversely affect the treatment process.

4.1.2 Distribution System. The distribution system in the Village of Waynesville has 214 connections served by both Wells No. 6 and 8. Based on the information provided by the facility operator, the distribution system material is comprised of $\frac{3}{4}$ to 6-in diameter cast iron pipe. As stated in Section 3.3.4, three residences within the Village's historic LCR network were selected for baseline and monthly distribution system water sampling to evaluate the effect of the treatment system on the distribution system water quality.

The Village collects water samples periodically from the distribution system, including monthly for bacterial analysis; quarterly for total arsenic; yearly for nitrate and nitrite; once every three years for LCR, inorganics, volatile organic compounds (VOCs), DBPs, and radionuclides for Well No. 8 water only; once every six years for radionuclides for Well No. 6 water; and once every nine years for pesticides.



4.2 Treatment Process Description

This section provides a technology description and site-specific details of the Peerless filtration system using GreensandPlus[™] media with an anthracite cap demonstrated at the Village of Waynesville, IL.

4.2.1 Technology Description. The Peerless filtration system uses GreensandPlus[™] media with an anthracite cap for arsenic removal from drinking water supplies. Manufactured by Inversand Company, GreensandPlus[™] has a silica sand core with a thermally-bonded manganese dioxide (MnO_2) coating, which is slightly different from the conventional manganese greensand, which is formulated from a glauconite greensand (with a process using IX properties of stabilized glauconite substrate to form an active MnO_2 coating). However, both media exhibit similar properties for water treatment purposes. According to the vendor, the performance of GreensandPlus[™] is expected to exceed that of the conventional manganese greensand because of its silica core, which is much harder than the glauconite greensand and can withstand greater pressure drops. The vendor also claims that GreensandPlus[™] is not

as prone to manganese stripping due to the thermal bonding process of MnO_2 to its silica core. The media has NSF International (NSF) Standard 61 approval for use in drinking water applications. Table 4-2 presents physical and operational properties of GreensandPlusTM and the anthracite cap.

Table 4-2. Physical Properties of Filtration Media

Parameter	Media	
	#1 Anthracite ^(a)	GreensandPlus ^{TM(b)}
Color and Physical Form	Black, dry, crushed granules 	Black, dry nodular granules 
Specific Gravity	1.6	~2.4
Bulk Density (g/cm^3)	0.8	1.4
Porosity	NA	~0.45
Mesh Size (U.S. Standard)	14 × 30	18 × 60
Effective Size (mm)	0.6–0.8	0.30–0.35
Uniformity Coefficient	<1.7	<1.6
Moisture Content (%)	<2.0	NA
pH Range	NA	6.2–8.5
Maximum Temperature	NA	No limit
Service Loading Rate (gpm/ft^2)	≥5	2–12
Backwash Rate (gpm/ft^2)	12–18	Minimum 12 at 55 °F

NA = not available

(a) http://www.clackcorp.com/water/pdf/anthracite_2354.pdf

(b) <http://www.inversand.com/product.htm>

The conventional manganese greensand has been used effectively for iron and manganese removal from source water for decades. Applicable removal mechanisms involved oxidation of soluble Fe(II) and Mn(II) to iron and manganese solids (as $\text{Fe}_2\text{O}_3\cdot\text{Fe}[\text{OH}]_3$ and MnO_2) and filtration and subsequent removal of accumulated solids from the greensand filter via backwash (Ficek, 1994). Meanwhile, the MnO_2 coating on manganese greensand (in the VI oxidation state) is reduced to manganese oxide (Mn_2O_3) in the III oxidation state. As it loses its oxidation capacity, the media is typically regenerated with KMnO_4 or NaOCl to restore its oxidation potential. The regeneration can be conducted either intermittently or continuously. Continuous regeneration continuously feeds KMnO_4 or NaOCl to the water to be treated by the media. In doing so, most, if not all, of soluble Fe(II) and Mn(II) would have been oxidized before the water is even in contact with manganese greensand. Therefore, the greensand would function only as a filtration media such as silica sand for gravity filtration.

When soluble As(III) also exists in source water (like Wells No. 6 and No. 8 water), soluble As(III) is oxidized to form soluble As(V), which is adsorbed onto and/or co-precipitated with iron solids also formed during the oxidation process. Arsenic-laden iron solids then are filtered by the greensand filter. Effective arsenic removal by chemical oxidation and greensand filtration has been demonstrated previously by various researchers (Magyar, 1992; Ficek, 1994; Pedersen, 2001) and at Licking Valley

High School in Newark, OH by Battelle (Chen et al., 2011a). Under the arsenic demonstration project, the process of chlorination and GreensandPlus™ filtration also was evaluated at Conneaut Lake Park in Conneaut Lake, PA (Chen et al., 2011c).

4.2.2 System Design and Treatment Process. The treatment process demonstrated at the Village of Waynesville consisted of NaMnO₄ oxidation and GreensandPlus™ filtration. A new 22 ft × 34 ft water treatment facility, located adjacent to Well No. 8 and the water tower, was constructed to house the treatment system. After treatment, treated water was stored in the water tower before entering the distribution system. Figure 4-4 is a generalized flow diagram of the treatment process including sampling locations and parameters analyzed during the demonstration period. Table 4-3 presents key system design parameters. The major components of the treatment process include:

- **Intake.** Raw water from Wells No. 6 and No. 8 was fed directly to the treatment system without being exposed to air. From system startup on July 15, 2009, through December 17, 2009, only Well No. 8 water was pumped to the treatment system at an average flowrate of 40.5 gpm, when work to synchronize the operation of Wells No. 6 with Well No. 8 was being completed. Activities included plumbing the raw water line from Well No. 6 to a common header with the raw water line for Well No. 8 and associated electrical connections. Upon completion of the work on December 18, 2009, combined raw water from Wells No. 6 and No. 8 was pumped to the treatment plant at an average flowrate of 84.4 gpm for the remainder of the performance evaluation study.
- **Sodium Permanganate Addition.** Liquid NaMnO₄ was preferred by the Village over KMnO₄ due to ease of handling. The NaMnO₄ addition system consisted of a 0.58-gal/hr (gph) LMI Milton Roy electronic metering pump (Model AA 941-358HI), a Digi-Pulse™ flow monitor (to transmit and monitor pulsating flow from the pump), a 50-gal, straight-sided polyethylene day tank, and an overhead mixer. A 20.0% NaMnO₄ stock solution was transferred from a 55-gal drum to the day tank using a manual crank pump. Tubing was used to deliver the NaMnO₄ solution from the day tank to an injection port located approximately 5 ft downstream of the raw water sampling location (IN). The speed and stroke of the chemical metering pump were set for a target dose rate of 6.0 mg/L (as NaMnO₄) based on results of the jar tests as discussed in Section 4.5.2. The NaMnO₄ addition system was synchronized with the operation of the well pumps. The chemical consumption was monitored daily using volumetric markings on the day tank. A low-level sensor was installed in the day tank to ensure proper chemical supplies. Figure 4-5 is a photograph of the NaMnO₄ addition system.
- **Anthracite/GreensandPlus™ Filtration.** The 96-gpm anthracite/GreensandPlus™ filtration system consisted of four 36-in × 72-in, 100 psi-rated carbon steel vessels coated with an epoxy interior lining (see Figure 4-6). The vessels were configured in parallel to allow both Well No. 6 and No. 8 to operate at a combined flowrate of 78 gpm. Each vessel was loaded with 6 ft³ of quartz support gravel, which was overlain with 14 ft³ of GreensandPlus™ and 7 ft³ of #1 anthracite for a respective bed depth of 24 and 12 in. Interconnected with 2-in ductile iron pipe, the vessels were equipped with five motor-actuated butterfly valves, which made up the valve tree as shown in Figure 4-6. To monitor system operations, the treatment system and individual vessels were equipped with flow meter/totalizers and pressure gauges (Figure 4-7). Table 4-4 presents technical specifications of each flow meter/totalizer and pressure gauge.

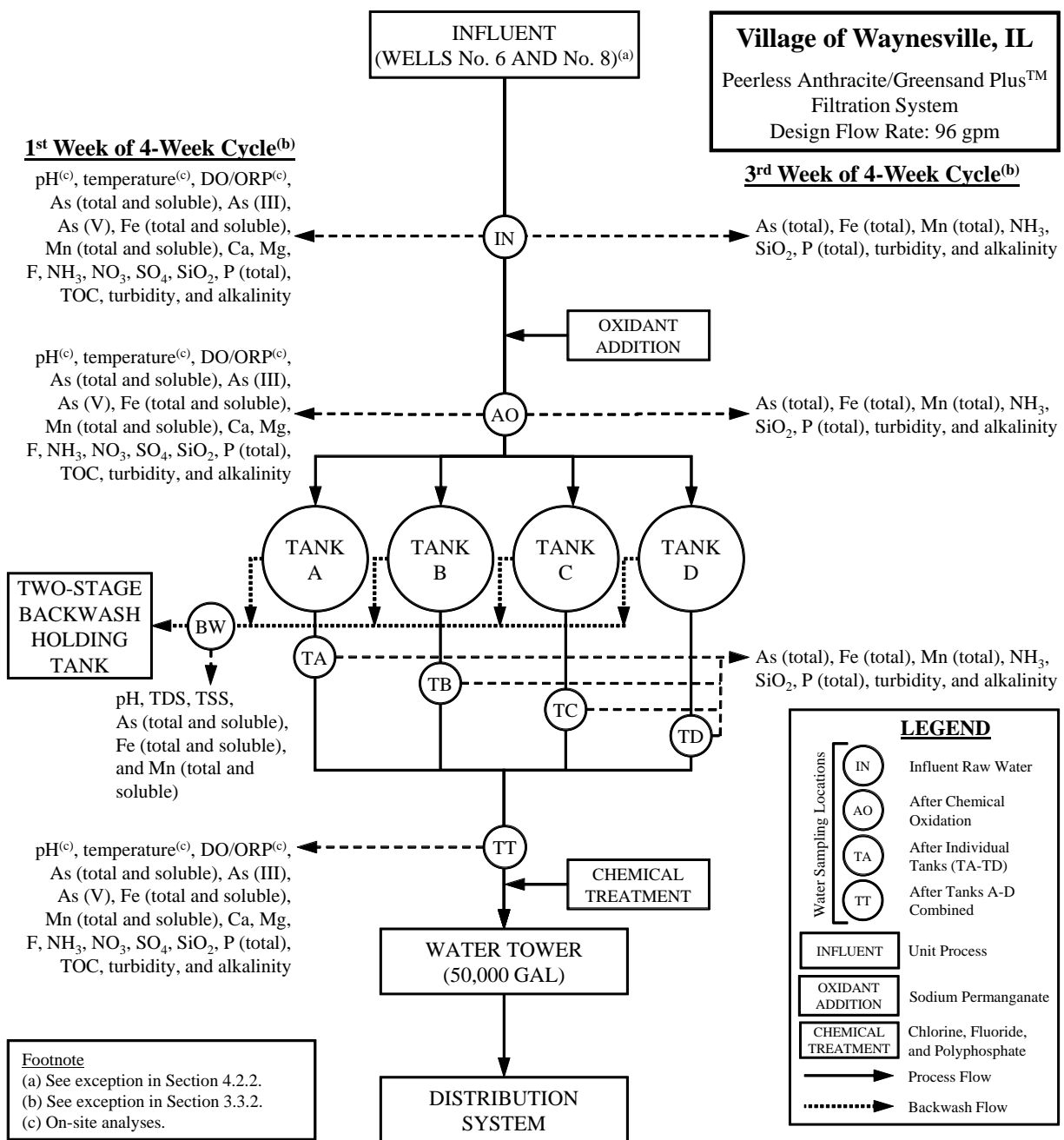


Figure 4-4. Process Flow Diagram and Sampling Locations

Table 4-3. Design Features of Peerless Anthracite/GreensandPlus™ Filtration System

Parameter	Value	Remarks
<i>Oxidation</i>		
NaMnO ₄ Target Dose Rate (mg/L as NaMnO ₄)	6.0–7.0	Based on jar test results
<i>Anthracite/GreensandPlus™ Filtration</i>		
No. of Vessels	4	–
Configuration	Parallel	–
Vessel Size (in)	36 D × 72 H	66 in side shell
Cross-Sectional Area (ft ² /vessel)	7.1	–
Media Depth (in/vessel)	12 (#1 Anthracite) 24 (GreensandPlus™)	–
Media Volume (ft ³ /vessel)	7 (#1 Anthracite) 14 (GreensandPlus™)	–
Design Flowrate (gpm)	96	24 gpm/vessel
Design Filtration Rate (gpm/ft ²)	3.4	
Δp Setpoint for Backwash (psi)	8	–
Backwash Frequency	Every 3 days	Vessels backwashed sequentially
Backwash Flowrate (gpm/vessel)	85	–
Backwash Duration (min/vessel)	8	–
Backwash Rate (gpm/ft ²)	12	–
Media Bed Expansion (%)	40	–
Fast Rinse Flowrate (gpm/vessel)	~80	–
Fast Rinse Duration (min/vessel)	2	–
Total Wastewater Production (gal/vessel)	840	–
<i>Post-Treatment</i>		
Chlorination Target Dose Rate (mg/L [as Cl ₂])	1.75	With a 12.5% NaOCl solution
Fluoridation Target Dose Rate (mg/L)	0.35	With a 19% H ₂ SiF ₆ solution
Polyphosphate Target Dose Rate (mg/L)	1.1	With a 34.5% Aqua Mag [®] solution

The motor actuated butterfly valves were controlled by an Allen-Bradley MicroLogix 1100 programmable logic controller (PLC) with an 8-in, C-more[®] EA7-T8C color touch panel (see Figure 4-7). In addition, the system had four manual butterfly valves at vessel inlets to divert incoming flow into each of the four vessels and four manual butterfly valves on treated effluent lines. The system also had a manual butterfly valve on the backwash line.

Based on the design flowrate to the treatment system, the filtration rate to each vessel was 3.4 gpm/ft², which is somewhat higher than the 10-state standard of 2 to 3 gpm/ft². The combined flowrate from both Wells No. 6 and No. 8 was lower than the design flowrate at approximately 76 gpm, equivalent to a filtration rate of 2.7 gpm/ft². IL EPA recommended during the project planning meeting that the system's filtration rate be kept within the 10-state standard of 2 to 3 gpm/ft².

- **Filter Backwash.** Filter backwash was accomplished using well water supplemented with the treated water from the water tower. Backwash can be automatically triggered by a differential pressure (Δp), a time, or a throughput setpoint. During the performance evaluation study, the treatment system was set to backwash every three days with the four vessels backwashed sequentially starting with Vessel A. From system startup through July 19, 2010, backwash for each vessel lasted for 8 min at a flowrate of 85 gpm/vessel. Backwash was followed by a filter to waste fast rinse for 2 min at a flowrate of over

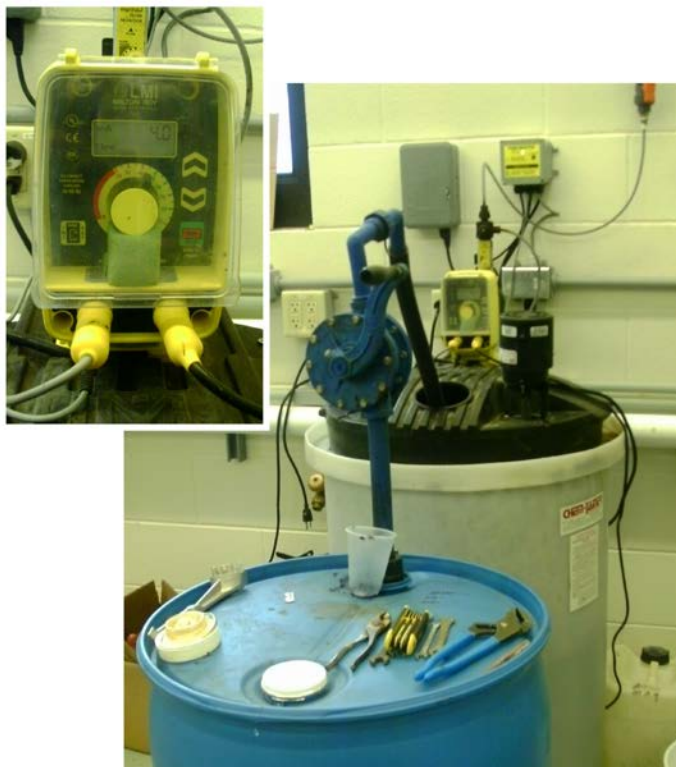


Figure 4-5. NaMnO₄ Addition System



Figure 4-6. Filtration Vessels and Valve Tree



Figure 4-7. System Instrumentation

(Clockwise from Top Left: System Effluent Pressure Gauge, System Effluent Flow Meter/Totalizer, System Influent Flow Meter/Totalizer, and PLC)

Table 4-4. Specifications of Flow Meters/Totalizers and Pressure Gauges

Equipment	Location	Brand	Type	Specifications
Master Totalizers	Well No. 6 Wellhead	Neptune	Turbine	2 in
	Well No. 8 Wellhead	Unknown	Turbine	2-in totalizer removed when pump house was taken down and piping re-routed to new facility
Flow Meters/Totalizers	System Inlet	ABB, MagMaster LoFlo	Electromagnetic	MFE101341101004ER; 4 in with a 0–100 gpm flow range
	Vessels A/B/C/D Inlet	Sparling, TigermagEPT™	Electromagnetic	FM626-02-8-1-0-0-0; 2 in with a 9–303 gpm flow range
	System Outlet			FM626-03-8-1-0-0-0; 3 in with a 20–664 gpm flow range
	Backwash Discharge			
Pressure Gauges	System Inlet/Outlet	Tetrice	¼-in NPT Bottom Connection	700LFSS4002LA110; 316 stainless steel with glycerin-filled dial
	Vessels A/B/C/D Inlet/Outlet			

80 gpm/vessel. Because of several operational issues as discussed in Section 4.4.2, the backwash duration was increased to 12 min/vessel with the same flowrate and the rinse duration was increased to 4 min/vessel with a significantly lower rinse flowrate of approximately 24 gpm/vessel. The wastewater produced was discharged via two 2,000-gal septic tanks in series with the first tank for particulate settling and the second tank for discharge to sewer. The Village’s sewer system has adequate reserved capacities for such

discharge and the Village was granted approval from IL EPA for backwash wastewater discharge.

- **Post-Treatment Chemical Additions.** The pre-existing chemical addition systems for chlorination (using NaOCl), fluoridation (using H_2SiF_6), and iron sequestration (using polyphosphate) were replaced with new addition systems housed in the new treatment plant building. Lines were re-routed to new injection points after the treatment system.

Each chemical addition system consisted of a LMI AA971 metering pump with a maximum flowrate of 0.42 gph, a 1000-mL calibration chamber, a Nalgene 2.5-gal carboy day tank, a Scaletron™ Model 2310 scale with digital read-out, and a 15-gal Chemtainer BP series bulk storage tank with stand. Solutions of NaOCl (12.5%), H_2SiF_6 (19%), and Aqua Mag® (34.5%) were diluted to 6%, 1.6%, and 4.93%, respectively. On a daily basis, the operator prepared each diluted solution in the 2.5-gal day tank by adding a concentrate from a 15-gal bulk storage tank to a specific level marked on each day tank via a spring-loaded transfer valve. The concentrate was then diluted with treated and softened water to another marked level on the day tank to achieve the desired concentration. The speed on each metering pump was set to 45, while the stroke was adjusted based on the flowrate to the treatment system to achieve the target chlorine (as Cl_2), fluoride, and polyphosphate dosages of 1.75, 0.35, and 1.10 mg/L, respectively.

During the demonstration period, the post-treatment chemical addition systems were synchronized with the operation of the well pumps. Chemical consumption was monitored by recording the weight (lb) on a daily basis from each of the three digital scales, which held the 2.5-gal carboy day tank. Figure 4-8 is a photograph of relevant chemical addition system components.



Figure 4-8. Post-Treatment Chemical Addition Systems
(Clockwise from Top Left: Calibration Chamber and Metering Pump,
Scaletron Digital Display, and Bulk Tank and Day Tank)

- **Water Storage.** After chemical additions, water was sent to the 100 ft-tall, 50,000-gal water tower for storage. The Well No. 6 and 8 well pumps turned on and off at 81.90 and 83.88 ft (or 35.50 and 36.36 psi), respectively. The head difference (i.e., 1.98 ft of water in the tower) corresponds to approximately 5,040 gal of water. From the water tower, treated water was either sent through to the distribution system or used for backwashing the filtration vessels.

4.3 System Installation

Installation and shakedown of the treatment system were completed by Crawford, Murphy & Tilly, Inc. (CMT Engineering) and G.A. Rich & Sons, Inc. (G.A. Rich) on May 8 and June 15, 2009, respectively. The following subsections summarize pre-demonstration study activities including permitting, building construction, and system offloading, installation, shakedown, and startup.

4.3.1 Permitting. Engineering plans and a permit application package were prepared by CMT Engineering, an engineering subcontractor to Peerless. The plans/package included a process flow diagram of the treatment system, mechanical drawings of the equipment, and a schematic of the equipment layout and were submitted to IL EPA on October 23, 2008. IL EPA approved the plans and issued a permit to the Village of Waynesville on January 9, 2009.

4.3.2 Building Construction. A new 22 ft × 34 ft water treatment facility, located adjacent to Well No. 8 and the water tower, was funded by the Village of Waynesville to house the new chemical addition and treatment systems. The building construction plan and permit application were prepared and submitted to IL EPA by CMT Engineering. IL EPA approved the plan and issued a permit to construct on January 22, 2008. Construction was performed by G.A. Rich from September 22, 2008, through April 30, 2009. In preparation for the new facility, the south end of the Village pavilion was removed so that the building foundation could be formed at the site. Figure 4-9 presents photographs of the new facility in several stages of construction and Figure 4-10 presents the layout of the new facility with the chemical addition and treatment systems.

4.3.3 Installation, Shakedown, and Startup. Treatment system components along with quartz support gravel, GreensandPlus™, and #1 anthracite arrived at the site on February 17, 2009. Figure 4-11 shows photographs of system component arrival and offloading. Installation of the treatment system began immediately after arrival by G.A. Rich. Activities included placing, anchoring, and plumbing of the four non-skid-mounted filtration vessels; placing and installation of the chemical addition systems (both pre- and post-treatment), and electrical connections. System installation was completed on May 8, 2009. Figure 4-12 shows photographs of the four filtration vessels immediately following offloading and after plumbing. Each vessel was hydrostatic tested at 130 psi in the vertical position prior to shipment and certified by the manufacturer, Quick Tanks, Inc. of Kendallville, IN.

From May 8 through 13, 2009, approximately 6 ft³ of quartz support gravel (including 2 ft³ each of ½ × ¼, #4, and #5), 14 ft³ of GreensandPlus™, and 7 ft³ of #1 anthracite were loaded sequentially into each filtration vessel and then backwashed at approximately 60 gpm/vessel to remove media fines. Freeboard measurements were made both before and after backwashing (see Table 4-5). Because freeboards were not measured following loading of support gravel, depths to gravel were estimated based on volumes of bottom domes and the straight shell-portion of the vessels. As shown in Table 4-5, average bed depths of GreensandPlus™ and #1 anthracite before backwashing were 17.4 and 11.4 in, respectively, equivalent to 10.3 and 6.8 ft³, respectively. Following backwashing, 0.1 to 0.9 ft³ of media was lost from each of the four filtration vessels. Except for Vessel A, the amounts of media lost were within the margin of errors. Because it could not be sure what (and how much) media was lost during backwashing, the media volumes obtained before backwashing were used for the following discussions.



Figure 4-9. Construction of New Treatment Plant Building
(Clockwise from Top: Concrete Forms for Building Foundation; Building Concrete Foundation; Completion of Building Walls and Roof; and Completed Water Treatment Plant Building)

While the average bed depth and volume of anthracite were comparable to the design values of 12 in and 7 ft³, respectively, the average bed depth and volume of GreensandPlus™ were significantly less than the design values of 24 in and 14 ft³, respectively. According to the vendor, 28 0.5-ft³ bags of GreensandPlus™ and seven 1.0-ft³ bags of #1 anthracite were loaded into each filtration vessel. Because freeboards to the top of gravel support were not measured, the 17.4 in and 10.3 ft³ GreensandPlus™ bed depth and volume were considered inaccurate. Therefore, for the purpose of discussions, 24 in and 14 ft³ were used as the GreensandPlus™ bed depth and volume, respectively.

Following backwashing, hydraulic testing was performed using a forward flow. At 24 gpm, no pressure loss was observed across Vessels B, C, and D. A 4-psi loss, however, was observed, but was linked later to a malfunctioning pressure gauge at the exit side of the vessel during a site visit by Battelle staff members on July 15, 2009. The result of a Bac-T sample taken after backwashing came back positive, prompting a decision to collect a separate Bac-T sample after the NaMnO₄ addition system became operational.

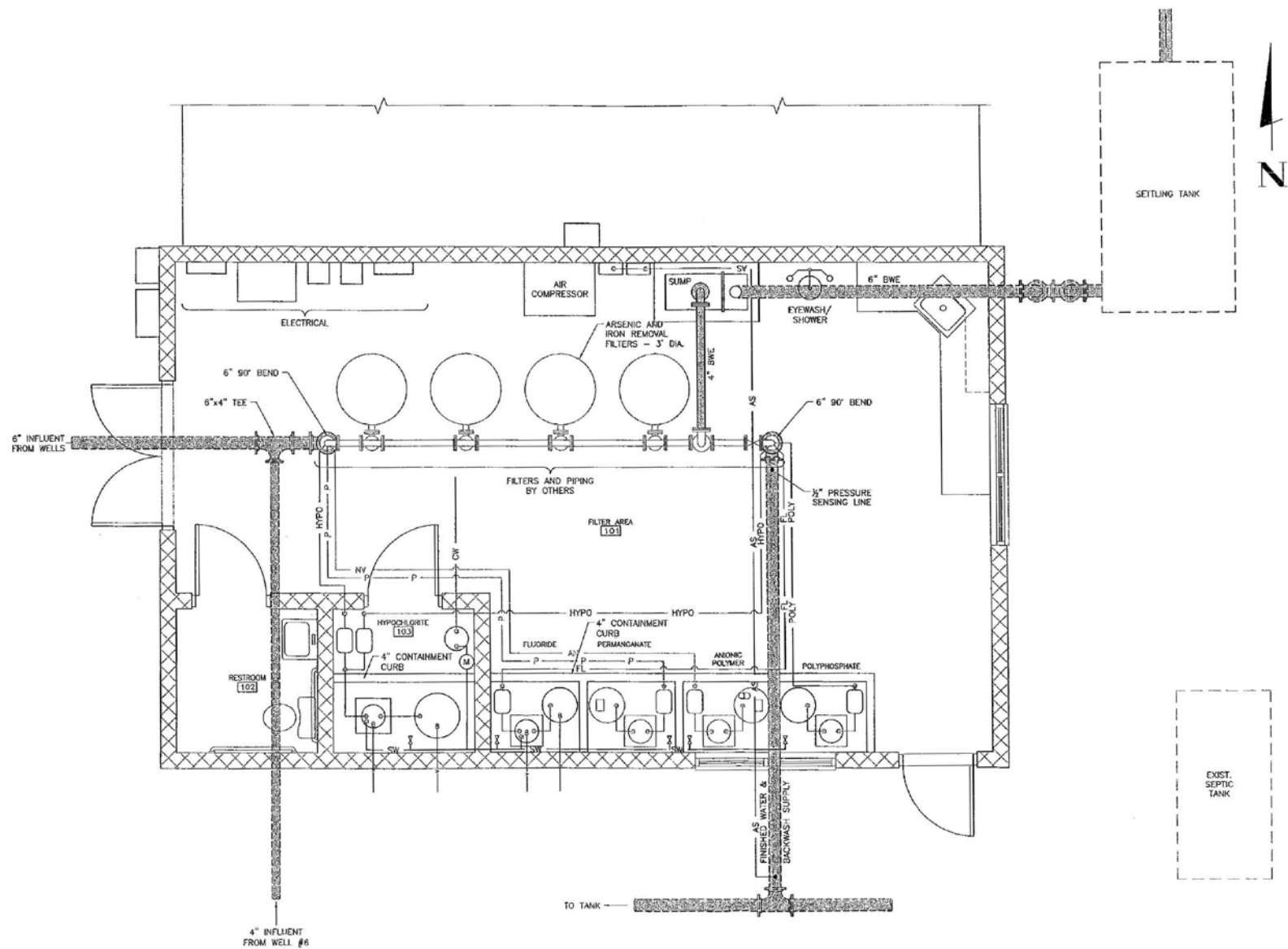


Figure 4-10. Layout of New Treatment Facility



Figure 4-11. Arrival and Offloading of System Components
(Top: Arrival of System Components on Flatbed; Clockwise from Left: Offloading of Filtration Vessels into Treatment Plant Building)



Figure 4-12. Filtration Vessels Before and After Plumbing

Table 4-5. Freeboard Measurements During System Installation

Measurements	Vessel A	Vessel B	Vessel C	Vessel D
To Top of Gravel (in)	61	61	61	61
<i>GreensandPlus™ (Before Backwash)</i>				
To Top of GreensandPlus™ (in)	43.5	43.8	43.5	43.5
GreensandPlus™ Bed Depth (in)	17.5	17.2	17.5	17.5
GreensandPlus™ Volume (ft ³)	10.3	10.2	10.3	10.3
<i>#1 Anthracite (Before Backwash)</i>				
To Top of #1 Anthracite (in)	32.0	32.3	32.3	32.0
#1 Anthracite Bed Depth (in)	11.5	11.5	11.2	11.5
#1 Anthracite Volume (ft ³)	6.8	6.8	6.6	6.8
<i>After Backwash</i>				
To Top of Anthracite (in)	33.5	33.0	32.5	32.5
Bed Depth Loss (in)	1.5	0.7	0.2	0.5
Volume Loss (ft ³)	0.9	0.4	0.1	0.3
Total Volume Loss (ft ³)	1.7			

On June 15, 2009, Peerless was onsite to perform preliminary startup services. Activities included working with CMT Engineering and G.A. Rich to install the NaMnO₄ addition system and performing GreensandPlus™ media conditioning using 6.0 to 7.0 mg/L NaMnO₄. Afterwards, another Bac-T sample was collected and the results were negative. After the vendor's visit, CMT Engineering and G.A. Rich worked to finish the installation and shakedown of the pre-treatment (i.e., NaMnO₄) and post-treatment chemical addition systems (i.e., chlorine, fluoride, and polyphosphate). All chemical addition systems were operational by July 8, 2009, and the performance evaluation study began on July 15, 2009.

On July 15, 2009, two Battelle staff members visited the facility to inspect the system and provide sample and data collection training to the operator. During inspections, several installation/operational issues were noted. Table 4-6 summarizes punch-list items, corrective actions taken, and resolution date after the system inspection.

Table 4-6. System Punch-List Operational Issues

Item No.	Punch-List/ Operational Issues	Corrective Action Taken	Resolution Date
1	Chemical day tank for NaMnO ₄ addition system required by IL EPA	IL EPA determined that the tank was not necessary upon further investigation	NA
2	No graduated markings on NaMnO ₄ chemical tank	Replaced original tank with a 50-gal, straight-sided polyethylene tank with graduated markings to more accurately measure chemical consumption	10/20/09
3	Effluent pressure gauge on Vessel A not working properly (low readings)	Replaced malfunctioning pressure gauge by operator	08/26/09
4	Rinse flowrate through each vessel not known	Conducted flow test to determine rinse flowrate to be >80 gpm per vessel; decreased flowrate to ~24 gpm	07/20/10
5	pH probe with temperature compensation for field meter not functioning properly	Replaced malfunctioning probe with a new probe	Immediately

NA = not applicable

4.4 System Operation

4.4.1 Operational Parameters. Operational data were collected during the period of July 15, 2009, through September 19, 2010, and are attached as Appendix A after tabulation. Table 4-7 summarizes key operational parameters.

Table 4-7. Summary of System Operational Parameters

Operational Parameter	Value/Condition			
Duration	07/15/09–09/19/10			
No. of Days System in Operation	156 (Well No. 6 only from 07/15/09 through 12/17/09) 276 (Wells No. 6 and No. 8 from 12/18/09 through 09/19/10)			
Average Daily Run Time (hr/day) ^(a)	11.8 (With Well No. 6 only) 5.8 (With Wells No. 6 and No. 8)			
Total Operating Time (hr) ^(b)	1,840 (With Well No. 6 only) 1,601 (With Wells No. 6 and No. 8)			
Throughput at System Inlet (gal) ^(c)	13,562,200			
Throughput at System Outlet (gal) ^(c)	12,603,800			
Throughput through Vessels (gal) ^(c)	<u>Vessel</u>	<u>Throughput</u>		
	A	3,425,390		
	B	3,414,210		
	C	3,464,390		
	D	3,294,210		
	System	13,598,200		
Instantaneous Flowrate (gpm)	<u>Vessel</u>	<u>Range^(d)</u>	<u>Average^(d)</u>	
	A	8.4–21.5/19.9–22.7	11.4/21.7	
	B	9.3–21.7/21.2–23.2	11.4/22.0	
	C	9.5–22.0/21.0–23.8	11.6/22.5	
	D	7.8–22.0/20.3–24.2	11.0/22.0	
	System ^(e)	32.9–45.6/81.7–88.1	40.5/84.4	
Filtration Rate (gpm/ft ²)	<u>Vessel</u>	<u>Range^(d)</u>	<u>Average^(d)</u>	
	A	1.2–3.0/2.8–3.2	1.6/3.1	
	B	1.3–3.1/3.0–3.3	1.6/3.1	
	C	1.3–3.1/3.0–3.4	1.6/3.2	
	D	1.1–3.1/2.9–3.4	1.6/3.2	
Operational Pressures (psi)	<u>Vessel</u>	<u>Inlet^(f)</u>	<u>Outlet^(f)</u>	<u>Δp^(f)</u>
	A	37 (35–46)	36 (31–38)	2 (0–13)
	B	38 (34–46)	37 (35–47)	1 (0–5)
	C	37 (34–45)	37 (35–42)	1 (0–4)
	D	37 (34–46)	38 (35–43)	2 (0–6)
	System	34 (32–38)	37 (30–39)	3 (0–5)

(a) Estimated based on volume throughput, total operating days, and average flowrate of respective operating period.

(b) Estimated based on average daily run time and total operating days of respective operating period.

(c) Based on readings of flow meters/totalizers shown in Table 4-4.

(d) Data before “/” for flowrate readings with only Well No. 6 in operation; data after “/” for flowrate readings with both wells in operation.

(e) Flowrate readings at system outlet.

(f) Data shown including average and range (in parentheses).

As noted in Section 4.2.2, since system startup through December 17, 2009, Well No. 6 was the only well in operation and it was not until December 18, 2009, that raw water from both Wells No. 6 and No. 8 was supplied to the treatment system. The system operated for a total of 1,840 hr when only Well No. 6 was in operation, and for 1,601 hr when both wells were in operation. These total operating times were estimated based on average daily run times (i.e., 11.8 and 5.8 hr, respectively) and number of days (i.e., 156 and 276 days, respectively) when the system was in operation. The average daily run times were estimated based on the system effluent volume throughput (i.e., 12,603,800 gal) and average flowrates (i.e. 40.5 and 84.4 gpm, respectively) as recorded by the flow meter/totalizer installed at the exit side of the system.

Throughputs recorded at the system inlet and outlet were 13,562,200 and 12,603,800 gal, with the inlet totalizer registering approximately 7.6% more flow than the outlet totalizer. Throughputs to individual filtration vessels ranged from 3,294,210 to 3,464,390 gal, indicating balanced flow through the four vessels. The total amount of water treated by the four filters was 13,598,200 gal, very close to the throughput value registered by the system inlet totalizer.

Based on readings taken from the system outlet totalizer, daily water demands ranged from 13,380 to 53,900 gal and averaged 29,217 gal, compared to the Village's average daily demand of approximately 29,000 gal provided by the operator prior to the performance evaluation study.

Instantaneous flowrates through the four filtration vessels ranged from 7.8 to 22.0 gpm and averaged 11.4 with Well No. 6 only, and from 19.9 to 24.2 gpm and averaged 22.1 gpm with both wells. Flowrates through the system ranged from 32.9 to 45.6 gpm and averaged 40.5 gpm with Well No. 6 only and from 81.7 to 88.1 gpm and averaged 84.4 gpm with both wells. The 84.4 gpm flow yielded a filtration rate of 3.2 gpm/ft², just above the 2 to 3 gpm/ft² range of the 10-state standard.

Inlet pressure readings to individual filtration vessels ranged from 34 to 46 psi and averaged 37 psi, which is similar to the average system inlet pressure of 34 psi. Vessel outlet pressure readings ranged from 31 to 47 psi and averaged 37 psi, identical to the average system outlet pressure. These inlet and outlet pressure readings reflected low pressure drops across all filtration vessels throughout the performance evaluation study, indicating adequate filter backwashing and frequency during system operations.

4.4.2 Backwash. The four filtration vessels were backwashed once every three days except during the first week of system operation when only one backwash event took place in the week and on March 3, June 25, and July 20, 2010, when backwash occurred either one day late or repeatedly the day after another backwash. In July 2010, the operator reported "yellow" and "pink" effluent during filter-to-waste rinse (although these issues could not be substantiated by Battelle), which prompted adjustments to the backwash and rinse duration from 8 to 12 min and from 2 to 4 min, respectively, on July 20, 2010. Meanwhile, it was brought to CMT Engineering and Battelle's attention that an excessively high flowrate (>80 gpm) was applied to each of the four filtration vessels during fast rinse and a joint decision was made to reduce the fast rinse flowrate to 24 gpm, the design filtration flowrate through each filtration vessel.

As shown in Table 4-8, from system startup through July 19, 2010, the system was backwashed 123 times, generating, on average, 3,100 gal of wastewater per backwash event. After backwash/fast rinse duration and fast rinse flowrate adjustments, the system was backwashed 21 times, generating, on average, 4,226 gal of wastewater per backwash event. These average amounts were very close to the would-be values of 3,360 and 4,464 gal, respectively, based on the set backwash/fast rinse durations and flowrates. The total amount of wastewater produced was 470,000 gal, equivalent to 3.7% of the total amount of water treated during the performance evaluation study.

Table 4-8. Summary of System Backwash Parameters

Parameter	From 07/15/09 Through 07/19/10	From 07/20/10 Through 09/19/10
Total Number of Backwash	123	21
Backwash Frequency	Every 3 days ^(a)	Every 3 days ^(b)
Backwash Duration (min/vessel)	8	12
Backwash Flowrate (gpm/vessel)	85	85
Fast Rinse Duration (min/vessel)	2	4
Fast Rinse Flowrate (gpm/vessel)	>80	24
Amount of Wastewater Produced per Backwash Event (gal)	3,100 (2,680–3,820)	4,226 (4,190–4,280)

(a) Except for three events during the first week of system operation and on 03/03/10 and 06/25/10.

(b) Except for one event on 07/20/10 (with a repeat backwash on the day after).

4.4.3 NaMnO₄ Injection. Figure 4-13 presents NaMnO₄ dosage applied to the treatment system during the performance evaluation study. NaMnO₄ dose rates ranged from 2.9 to 14.6 mg/L and averaged 6.9 mg/L (as NaMnO₄). This average dose rate was twice the target dose rate of 3.4 mg/L (as NaMnO₄) determined by the jar tests. No pink color was observed by the operator or reported by customers.

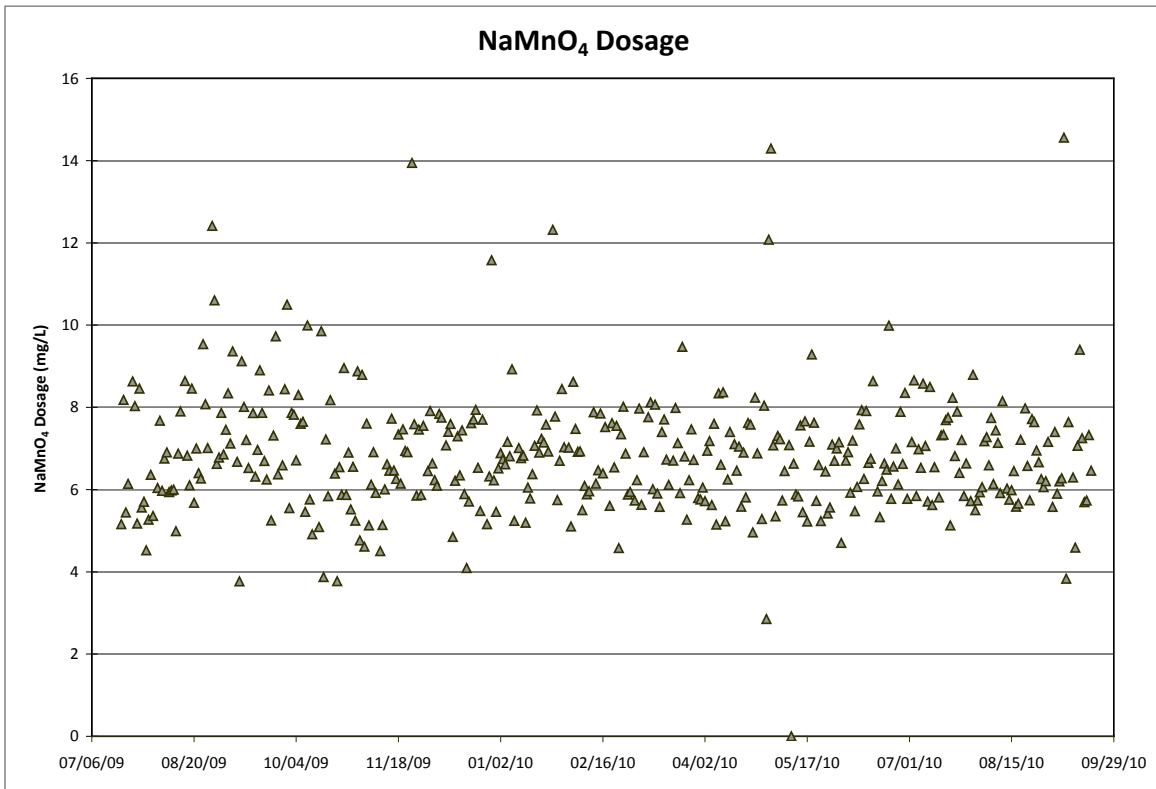


Figure 4-13. NaMnO₄ Dosage

4.4.4 Residual Management. Residuals produced by the Peerless anthracite/GreensandPlus™ filtration system included both backwash and rinse wastewater containing arsenic-laden iron particles. The wastewater was discharged to a sump, which emptied by gravity into the two 2,000-gal septic tanks in series. IL EPA issued a permit to the Village on November 26, 2007, to discharge the wastewater to the sanitary sewer system.

After the demonstration period on November 11, 2010, and April 21, 2011, sludge accumulated in the septic tanks was pumped and transported by Morris Septic of Rock Falls, IL to the Clinton Sanitary District for disposal.

4.4.5 System/Operation Reliability and Simplicity. There was no downtime for the treatment system throughout the performance evaluation period. However, the system experienced a few operational issues, which, along with the corrective actions taken, are described below.

On November 11, 2009, the backwash flow meter/totalizer registered a reading that was much higher than the would-be value of approximately 3,100 gal per backwash event. After discussing with the equipment vendor, it was discovered that the flow meter/totalizer continued to register even when the system was not being backwashed. On December 9, 2009, a Peerless engineer re-programmed the flow meter/totalizer, which operated properly thereafter.

On January 25, February 24, March 23, 2010, and June 15, 2010, treatment plant sampling results showed abnormally high levels of fluoride (from 6.0 to 16.9 mg/L) and phosphorus (from 4,008 to 6,627 µg/L [as P]) at the TT location, which were located within 2 ft from the down-gradient post-treatment chemical addition points. Bleeding of post treatment chemicals when there was no process flow was thought to have caused the problem. However, this might not be the sole cause of the high concentrations when it was discovered that post-treatment chemical additions were triggered by the well pumps. Due to the small capacity of the elevated distribution system storage tank, the well pumps turned on during backwash to augment backwash water. This caused the treated water to be double-dosed during backwashing and dosed again during the filter-to-waste rinse and normal system operation. When this was discovered, the operator was instructed to manually turn off the post-treatment chemical addition systems during backwashing until re-wiring to the finished water flow meter could be done. Because of concerns over this cross-contamination issue, speciation samples for the combined system effluent were collected from the TA sampling location on April 22, May 19, August 18, and September 15, 2010. Re-wiring, however, was not complete before the end of the performance evaluation study.

On May 19, June 3, and June 9, 2010, CMT Engineering and Battelle conducted a joint investigation on backwash due to the operator's concerns over "pink and yellow" effluent during the filter-to-waste rinse. The investigation also re-evaluated the reasonableness of using a high flowrate of over 80 gpm/vessel to rinse the filters. It was determined that this rinse flowrate could cause damages to GreensandPlus™ media and should be significantly reduced to the design service flowrate of 24 gpm/vessel; CMT Engineering and Peerless went ahead to adjust the flowrate accordingly. As to the "pink and yellow" effluent issue, it was determined that it most likely was caused by the NaMnO₄ dispensed into the rinse water (and the backwash water) during the backwash cycle and should not present a problem especially since the rinse water would be discharged into the septic tanks before being emptied to the sewer system.

The system O&M and operator skill requirements are discussed below in relation to pre- and post-treatment requirements, levels of system automation, operator skill requirements, preventive maintenance activities, and frequency of chemical handling and inventory requirements.

Pre- and Post-Treatment Requirements. Pretreatment consisted of NaMnO₄ addition using a 20% NaMnO₄ stock solution to oxidize soluble As(III) to soluble As(V), and formation of filterable arsenic-

laden iron particles prior to GreensandPlus™ filtration. The operator tracked solution levels in the chemical day tanks for adequate chemical consumption. Post-treatment consisted of chlorination, fluoridation, and polyphosphate using 12.5% NaOCl, 19% H₂SiF₆, and 34.5% Aqua Mag®, respectively, as discussed in Section 4.2.2. The operator monitored chemical consumption daily by recording the weight (lb) from each of the three digital scales, which held the day tanks.

System Automation. The low-level sensor (at 81.90 ft) in the 50,000-gal water tower triggered the Well No. 8 pump, which then triggered the Well No. 6 pump. Wells No. 6 and No. 8 provided water to the treatment system at a combined flowrate of approximately 84 gpm. Once the water level in the tower reached the high level at 83.88 ft, it shut off the Well No. 8 and then Well No. 6 pumps. Each vessel had five motor-actuated butterfly valves, three manual isolation butterfly valves (on inlet, outlet, and backwash lines), and one manual throttling valve (on the outlet line). Valve sequences were controlled by an Allen-Bradley MicroLogix 1100 PLC. An 8-in, C-more® EA7-T8C color touch panel interface allowed the operator to monitor system parameters, change system setpoints, and check alarm status.

The system was fitted with controls for automatic backwash. The automated portion of the system did not require routine O&M; however, the operator's awareness and abilities to detect and troubleshoot system irregularities were necessary to maintain system operations. The NaMnO₄ addition system was interlocked with the operation of the two well pumps. The post-treatment chemical addition systems (i.e., NaOCl, H₂SiF₆, and Aqua Mag®) were interlocked with the well pump. Due to concerns over cross-contamination by the post-treatment chemicals, plans were made to re-wire these chemical addition systems to the flow meter/totalizer installed at the system outlet. To maintain system operation, the only requirement was for the operator to continue to refill the chemical day tanks. The equipment vendor and especially CMT Engineering provided hands-on training and assistance to the operator during system installation, shakedown, and startup, and throughout the demonstration period.

Operator Skill Requirements. Under normal operating conditions, the skills required to operate the treatment system were moderate. The operator's knowledge of the system limitations and typical operational parameters were critical in achieving system performance objectives. Typically, the operator was onsite daily and spent approximately 20 min during each visit to perform visual inspections and record system operational parameters on the log sheets. The operator also monitored and refilled the NaMnO₄, NaOCl, H₂SiF₆, and Aqua Mag® day tanks and performed general maintenance of all chemical addition systems.

Operator training began onsite with the equipment vendor and CMT Engineering during system installation, shakedown, and startup. However, over the demonstration period, the operator gained invaluable operational skills through hands-on experience and additional assistance from CMT Engineering and the operator of the water system at Geneseo Hills Subdivision in Geneseo, IL.

IL EPA requires that the system operator at the Village of Waynesville hold at least a Class B IL EPA drinking water operator certification. IL EPA drinking water operator certifications are classified from Class A through D with Class A being the highest, requiring the most education, experience, and training. Licensing eligibility requirements are based on education, experience, and related training and incrementally increase with each licensing level. Specifically, Class B requires a high school diploma or equivalent and three years of responsible experience in water supply operation.

Preventive Maintenance Activities. Preventive maintenance tasks included: (1) checking the flow meters and pressure gauges; (2) inspecting treatment system vessels, piping, and valves for leaks; (3) monitoring chemical levels in all day tanks to ensure proper chemical usage; and (4) checking the chemical addition systems for proper operations and supply lines for leaks and adequate pressure. Typically, the operator performed these duties on a daily basis when onsite for routine activities.

Chemical Handling and Inventory Requirements. The operator tracked usage of all chemicals on a daily basis by measuring solution levels in all chemical day tanks and refilled the tanks as needed. A 20% NaMnO₄ stock solution, supplied in 55-gal polyethylene drums by Brenntag Mid-South, Inc., was transferred by a hand pump to the day tank and injected into raw water without dilution. One drum of NaMnO₄ stock solution was ordered from Brenntag Mid-South, Inc. approximately every two months along with post-treatment chemicals (i.e., NaOCl, H₂SiF₆, and Aqua Mag[®]). The NaOCl, H₂SiF₆, and Aqua Mag[®] stock solutions (as described in Section 4.2.2) were supplied in 5, 15, and 15-gal carboys, respectively.

4.5 Jar Test Results

4.5.1 Oxidant Demand Studies. Table 4-9 presents results of the chlorine demand study. After the prescribed 20 min contact time, the two lowest doses (i.e., 2.6 and 4.9 mg/L [as Cl₂]) resulted in a negligible total chlorine residual. After these analyses, it was concluded that the chlorine demand of Well No. 8 raw water was greater than 4.6 mg/L (as Cl₂). The next four doses (7.0, 9.1, 12.8 and 16.4 mg/L [as Cl₂]) yielded a demand within a reasonably narrow range of 6.2 to 8.5 mg/L (as Cl₂). These values were used to calculate the average and standard deviation of chlorine demand, which were 7.2 and 1.0 mg/L (as Cl₂), respectively (coefficient of variation of 14%). This averaged value was used as the basis for choosing doses of NaOCl for the subsequent arsenic/iron removal and DBP formation potential study.

Table 4-9. Results of Chlorine Demand Study for Well No. 8 Raw Water

Date	Initial Total Chlorine Dose (mg/L)	20 min Total Chlorine Residual (mg/L)	20 min Total Chlorine Demand (mg/L)
04/23/09	0.0	0.0	-
	2.6	0.2 ^(a)	>2.4
	4.9	0.3 ^(a)	>4.6
05/20/09	7.0	0.8	6.2
	9.1	2.2	6.9
	12.8	5.5	7.3
	16.4	7.9	8.5

(a) Values not significantly different from background.

Table 4-10 presents results of the permanganate demand study. As anticipated, the raw water with no added KMnO₄ measured below the MDL for KMnO₄ and was used as a control. Four doses (6.0, 8.5, 11.5 and 17.5 mg/L [as KMnO₄]) were used to determine the average KMnO₄ demand of the Well No. 8 raw water, which was estimated to be 3.4 mg/L (as KMnO₄). The measurements had a standard deviation of 0.8 mg/L (as KMnO₄) and a coefficient of variation of 23%. This value was used as the basis for choosing an KMnO₄ dose for the subsequent DBP formation potential study.

4.5.2 Arsenic/Iron Removal and DBP Formation Potential Studies. Table 4-11 presents measured water quality parameters for the jar tests. The second column of this table shows results of Well No. 8 water, which are used to benchmark changes caused by the introduction of an oxidant. The raw water results were consistent with the data collected previously by EPA, IL EPA, and Battelle during the introductory meeting on December 5, 2006 (see Table 4-1), and throughout the performance evaluation study between July 15, 2009, and September 19, 2010 (see Tables 4-12 and 4-13).

Table 4-10. Results of Permanganate Demand Study for Well No. 8 Raw Water

Date	Initial KMnO ₄ Dose (mg/L)	20 min KMnO ₄ Residual (mg/L)	20 min KMnO ₄ Demand (mg/L)
05/20/09	0.0	0.0	-
	6.0	3.3	2.7
	8.5	5.3	3.2
	11.5	7.9	3.6
	17.5	13.1	4.4

Table 4-11. Results for Arsenic/Iron Removal and DBP Formation Potential Studies

Parameters	Raw Water	KMnO ₄	NaOCl #1	NaOCl #2
<i>Jar Test Parameters</i>				
Oxidant Dose (mg/L [as Cl ₂] or [KMnO ₄])	0.0	6.0	8.0	10.0
Reaction time (min)	0	20	20	120
Total Chlorine (mg/L)	0.0	3.0 ^(a)	2.0	3.1
<i>Onsite Measurements</i>				
pH (S.U.)	7.3	7.6	6.7	7.5
Temperature (°C)	15.2	16.8	17.2	20.2
ORP (mV)	-55	225	95	310
Dissolved Oxygen (mg/L)	1.0	1.1	5.0	1.1
<i>Metals and Miscellaneous Analytes</i>				
Ammonia (mg/L [as N])	4.4	3.7	4.1	3.7
Total Organic Carbon (mg/L)	7.6	9.1	NA	7.4
Phosphorus (µg/L)	112	114	112	111
As (total) (µg/L)	50.1	48.4	48.7	48.9
As (soluble) (µg/L)	36.4	5.7	19.2	12.5
As particulate (µg/L)	13.7	42.7	29.5	36.4
As(III) (µg/L)	27.2	0.6	8.9	5.4
As(V) (µg/L)	9.2	5.1	10.3	7.1
Fe (total) (µg/L)	2,151	2,141	2,053	2,149
Fe (soluble) (µg/L)	2,339	56.3	251	<25
Mn (total) (µg/L)	22.6	1,443	21.9	22.5
Mn (soluble) (µg/L)	22.7	279	22.1	22.0
<i>Disinfection Byproducts</i>				
Chloroform (µg/L)	NM	<0.5	4.9	6.8
Bromodichloromethane (µg/L)	NM	<0.5	<0.5	<0.5
Dibromochloromethane (µg/L)	NM	<0.5	<0.5	<0.5
Bromoform (µg/L)	NM	<0.5	<0.5	<0.5
Total Trihalomethanes (µg/L)	NM	<2	4.9	6.8
Dibromoacetic Acid (µg/L)	NM	<1	<1	<1
Dichloroacetic Acid (µg/L)	NM	<1	<1	1.3
Monobromoacetic Acid (µg/L)	NM	<1	<1	<1
Monochloroacetic Acid (µg/L)	NM	<2	<2	<2
Trichloroacetic Acid (µg/L)	NM	<1	<1	1.4
HAA5 (µg/L)	NM	<6	<6	2.7

(a) Measured using DPD method for KMnO₄ with a correction factor of 0.893 (Carus Corporation, 2001).

(b) This value considered erroneous due most likely to an instrument error.

NM = not measured

Chlorine as an Oxidant. Results of the arsenic/iron removal and DBP formation potential study using chlorine as an oxidant are presented in the two columns labeled “NaOCl #1” (for 8 mg/L [as Cl₂] dose) and “NaOCl #2” (10 mg/L [as Cl₂] dose). With both chlorine dose rates, ORP values increased progressively, as expected, from -55 mV to as high as 310 mV. The DO level remained relatively unchanged for NaOCl #2, but was significantly elevated at 5.0 mg/L for NaOCl #1. This elevated DO level was thought to be an experimental error. With 8.0 mg/L of chlorine (as Cl₂) and 20 min of contact time, the soluble As(III) concentration was reduced from 27.2 to 8.9 µg/L. Even with 10 mg/L of chlorine (as Cl₂) and 120 min of contact time, the soluble As(III) concentration was reduced to only 5.4 µg/L. Incomplete As(III) oxidation most likely was caused by the presence of elevated ammonia (4.4 mg/L [as N]), which reacted with chlorine to form chloramines. Ghurye and Clifford (2001) reported that pre-formed monochloramines were ineffective for As(III) oxidation and that limited oxidation could be achieved when monochloramine was formed in situ. The chlorine added might have reacted initially with both soluble As(III) and ammonia in water before it was quenched by ammonia to form chloramines (Frank and Clifford, 1986).

Incomplete Fe(II) oxidation (from 2,339 to 251 µg/L) also was observed with 8 mg/L of chlorine (as Cl₂) and 20 min of contact time. Similar to soluble As(III), some soluble iron might have been oxidized initially by free chlorine before free chlorine reacted with ammonia to form chloramines. Chloramines (preformed or formed in situ) were less effective in oxidizing soluble iron than free chlorine. With an even larger chlorine dose (10.0 mg/L as [Cl₂]) and a longer contact time (120 min), the soluble iron concentration was reduced to below the MDL of 25 µg/L. This more complete oxidation might have been caused by the greater chlorine dose rate and/or the prolonged contact time (Vikesland and Valentine, 2002).

Due to incomplete soluble iron oxidation, as much as 10.3 µg/L of soluble As(V) remained in water under NaOCl #1. This, along with the soluble As(III), left the soluble arsenic concentration well above 10 µg/L (i.e., 19.2 µg/L). Therefore, even with complete removal of particulate arsenic via GreensandPlus™ filtration, the remaining soluble arsenic concentration in the treated water would be well above the 10-µg/L MCL, rendering the seemingly overabundant soluble iron (at a soluble iron to soluble arsenic ratio of 64.2) ineffective in arsenic removal. With 10.0 mg/L (as [Cl₂]) of chlorine and 120 min of contact time, the soluble As(V) concentration was reduced to 7.1 µg/L, which, although lower, was not sufficient to compensate the 5.4 µg/L of soluble As(III) still in the treated water.

Manganese is more difficult to oxidize compared to arsenic and iron, especially when present in high TOC waters (Knocke et al., 1987); therefore, soluble manganese levels remained essentially unchanged at 22 µg/L after chlorine additions.

Neither chlorine addition scenario was capable of generating TTHMs or HAA5 in appreciable amounts. This is an expected result, as waters high in ammonia concentration (even when subjected to excessive chlorination) tend not to produce excessive amounts of DBPs (Bougéard et al., 2010; Sun et al., 2009; Amy et al., 1984). Thus, formation of DBPs under these chlorine addition scenarios is not considered a water quality issue.

Although not forming DBPs, chlorination at 8 or 10 mg/L (as Cl₂) not only is ineffective in removing arsenic but also is expensive, has potential to cause taste and odor issues, requires more operation attention, and is not in compliance with the Stage 1 Disinfectants and Disinfection Byproducts Rule (EPA, 1998), which stipulates MRDLs and MRDLGs of 4 mg/L (as Cl₂).

KMnO₄ as an Oxidant. The final jar test involved 6.0 mg/L of KMnO₄ addition and 20 min of contact time. 6.0 mg/L rather than 3.4 mg/L of KMnO₄ was used because a larger dose might be needed to offset the TOC effect and form more filterable MnO₂ particles (Shiao et al., 2009). KMnO₄ at this dose and

contact time was able to thoroughly oxidize soluble As(III), leaving only 0.6 µg/L in the treated water. Further, the As(V) formed was sufficiently removed by iron solids, reducing the soluble arsenic concentration to well below the 10-µg/L MCL (at 5.7 µg/L). Thus, KMnO₄ at 6.0 mg/L and 20 min contact time is effective in oxidizing source water and promoting adsorption/co-precipitation of soluble As(V) onto/with iron particles. Assuming that arsenic-laden iron particles can be fully removed via GreensandPlus™ filtration (i.e., no particulate breakthrough), total arsenic concentrations in the finished water can be reduced to below 6.0 µg/L. Iron, too, was sufficiently oxidized to close to the MDL.

Effective oxidation of soluble As(III) and soluble Fe(II) with permanganate has been extensively reported in the literature (Ghurye and Clifford, 2001). A few arsenic demonstration projects also used KMnO₄ or NaMnO₄ as an oxidant to treat soluble As(III) and soluble Fe(II) while having elevated levels of TOC and ammonia in source waters (Chen et al., 2011b; Shiao et al., 2009). One example was Big Sauk Lake Mobile Home Park in Sauk Centre, MN, (Shiao et al., 2009) where, although not as high as that observed at the Village of Waynsville, IL, TOC and ammonia were both elevated at 3.3 mg/L and 1.2 mg/L (as N), respectively (on average). After KMnO₄ addition, soluble As(III) concentrations were significantly reduced from 21.9 to 1.0 µg/L and particulate arsenic levels were correspondingly elevated from 2.2 to 22.7 µg/L. The near complete precipitation of soluble iron observed suggested effective Fe(II) oxidation even in the presence of elevated TOC. Researchers have reported that Fe(II)-KMnO₄ reaction rates are more rapid than KMnO₄-DOM interactions (Knocke et al., 1994). It appeared that the elevated TOC levels in raw water did not adversely impact soluble As(III) and soluble Fe(II) oxidation, similar to what was observed by Ghurye and Clifford (2001).

Similar to DBP formation potential results for the two chlorine doses, addition of 6.0 mg/L KMnO₄ did not produce significant amounts of DBPs either. TTHMs were measured at 6.8 µg/L and HAA5 at 2.7 µg/L. Both of these values are significantly lower than the respective MCLs for the compounds and, thus, DBP formation under this KMnO₄ addition scenario is not considered a water quality issue.

Given both oxidants' performance in oxidizing soluble As(III) and Fe(II) and forming arsenic-laden solids, NaMnO₄ at 6.0 to 7.0 mg/L was chosen as the oxidant for treating water from Wells No. 6 and No. 8. As mentioned earlier, one inherent challenge with the use of KMnO₄, especially with the presence of elevated TOC, is to keep manganese levels below the SMCL in treated water. For example, addition of 6.0 mg/L KMnO₄ in this jar test imparts 2,080 µg/L of manganese (as Mn) to the treated water. If the manganese remains in the colloidal form, it will pass through the filter media to the finished water. If the manganese is fully oxidized and present as filterable particles, they will increase loading to the filter media and may result in severely shortened useful filter run lengths. The results of this jar test indicate that the majority of manganese was in the particulate form (1,443 vs. 279 µg/L in the soluble form). These data suggest that in an event of complete particulate removal by the GreensandPlus™ filters, the finished water would contain 279 µg/L of "soluble" manganese, present either as MnO₄⁻ (due to KMnO₄ overdosing) or as colloidal MnO₂. It will be important to monitor filter removal performance to avoid manganese breakthrough and exceedance of the 50 µg/L SMCL.

4.6 System Performance

The performance of the C/F system was evaluated based on analyses of water samples collected across the treatment plant, during the media backwash, and from the distribution system.

4.6.1 Treatment Plant Sampling. From July 15, 2009, through September 19, 2010, treatment plant water samples were collected on 30 occasions, including three duplicate and 15 speciation sampling events. Table 4-12 summarizes analytical results of arsenic, iron, and manganese measured across the treatment train at the IN, AO, TA, TB, TC, TD, and TT locations. Table 4-13 summarizes results of other water quality parameters. A complete set of analytical results for the demonstration study are provided as Appendix B.

Table 4-12. Summary of Arsenic, Iron, and Manganese Analytical Results

Parameter	Unit	Sample Location	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
As (total)	µg/L	IN	30	23.9	45.2	33.1	6.5
	µg/L	AO	29 ^(a)	18.9	43.2	31.3	7.0
	µg/L	TA	19	0.5	5.2	2.6	1.3
	µg/L	TB	15	0.2	3.9	2.2	1.0
	µg/L	TC	15	0.1	3.6	2.2	1.0
	µg/L	TD	15	0.4	3.1	2.0	0.7
	µg/L	TT	11	2.5	4.6	3.4	0.7
As (soluble)	µg/L	IN	15	24.1	40.0	31.4	4.6
	µg/L	AO	13 ^(b)	2.1	5.0	3.5	0.9
	µg/L	TA	4	1.6	2.9	2.2	0.5
	µg/L	TT	11	1.8	6.0	3.3	1.1
As (particulate)	µg/L	IN	15	<0.1	12.0	2.2	3.5
	µg/L	AO	13 ^(b)	21.1	36.4	27.1	5.2
	µg/L	TA	4	<0.1	1.7	0.5	0.8
	µg/L	TT	11	<0.1	2.1	0.5	0.6
As(III)	µg/L	IN	15	13.3	32.2	24.1	5.6
	µg/L	AO	13 ^(b)	<0.1	0.9	0.6	0.3
	µg/L	TA	4	0.3	0.6	0.5	0.2
	µg/L	TT	11	<0.1	1.2	0.7	0.3
As(V)	µg/L	IN	15	<0.1	15.2	7.7	4.1
	µg/L	AO	13 ^(b)	1.8	4.3	3.0	0.8
	µg/L	TA	4	1.4	2.3	1.7	0.4
	µg/L	TT	11	1.2	5.6	2.6	1.1
Fe (total)	µg/L	IN	30	1,939	2,720	2,298	203
	µg/L	AO	29 ^(a)	1,610	2,637	2,283	243
	µg/L	TA	19	<25	353	65.1	109
	µg/L	TB	15	<25	248	54.4	87.2
	µg/L	TC	15	<25	222	46.1	71.7
	µg/L	TD	15	<25	136	33.1	43.6
	µg/L	TT	11	<25	150	34.9	50.3
Fe (soluble)	µg/L	IN	15	1,939	2,841	2,277	268
	µg/L	AO	13 ^(b)	<25	147	48.1	46.7
	µg/L	TA	3 ^(c)	<25	<25	<25	–
	µg/L	TT	11	<25	<25	<25	–
Mn (total)	µg/L	IN	30	21.2	108	33.1	19.6
	µg/L	AO	28 ^(a,c)	1,331	3,981	2,451	647
	µg/L	TA	19	5.2	349	69.7	92.0
	µg/L	TB	15	7.0	236	91.6	69.1
	µg/L	TC	15	8.4	170	82.5	51.1
	µg/L	TD	15	32.4	162	98.9	35.4
	µg/L	TT	11	38.0	119	70.6	24.2
Mn (soluble)	µg/L	IN	15	21.3	73.6	32.1	13.4
	µg/L	AO	13 ^(b)	26.4	1,567	765	414
	µg/L	TA	4	4.9	30.4	15.1	10.9
	µg/L	TT	11	13.8	94.9	54.6	23.2

(a) 06/30/10 result considered an outlier and not included in calculations.

(b) 08/19/09 and 09/15/09 results considered outliers and not included in calculations.

(c) 09/15/10 result considered an outlier and not included in calculations.

Table 4-13. Summary of Other Water Quality Parameter Results

Parameter	Unit	Sample Location	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Alkalinity (as CaCO ₃)	mg/L	IN	30	542	651	599	27.4
	mg/L	AO	30	548	670	611	31.1
	mg/L	TA	19	536	675	612	35.7
	mg/L	TB	15	535	697	602	37.7
	mg/L	TC	15	538	629	593	27.7
	mg/L	TD	15	516	627	592	26.8
	mg/L	TT	11	563	630	596	20.0
Ammonia (as N)	mg/L	IN	30	3.4	4.2	3.8	0.2
	mg/L	AO	30	3.4	5.8	3.9	0.4
	mg/L	TA	19	3.4	4.3	3.9	0.3
	mg/L	TB	15	3.3	4.1	3.8	0.2
	mg/L	TC	15	3.3	4.3	3.8	0.3
	mg/L	TD	15	3.6	4.2	3.8	0.2
	mg/L	TT	6 ^(a)	3.5	4.0	3.7	0.2
Fluoride	mg/L	IN	15	0.3	0.6	0.4	0.1
	mg/L	AO	15	0.3	1.6	0.5	0.3
	mg/L	TA	4	0.3	0.7	0.5	0.1
	mg/L	TT	6 ^(a)	0.5	1.2	0.7	0.3
Sulfate	mg/L	IN	15	<0.1	<0.1	<0.1	–
	mg/L	AO	15	<0.1	0.1	<0.1	–
	mg/L	TA	4	<0.1	0.1	<0.1	–
	mg/L	TT	11	<0.1	0.7	0.2	0.2
Nitrate (as N)	mg/L	IN	15	<0.05	<0.05	<0.05	–
	mg/L	AO	15	<0.05	<0.05	<0.05	–
	mg/L	TA	4	<0.05	<0.05	<0.05	–
	mg/L	TT	11	<0.05	0.2	<0.05	0.06
P (as P)	µg/L	IN	30	27.2	141	89.1	21.5
	µg/L	AO	29 ^(b)	27.0	135	87.4	19.1
	µg/L	TA	19	<10	42.3	14.8	10.6
	µg/L	TB	15	<10	34.6	11.7	8.7
	µg/L	TC	15	<10	35.8	12.0	9.3
	µg/L	TD	15	<10	36.1	12.3	10.7
	µg/L	TT	5 ^(c)	18.5	51.6	26.7	14.0
Silica (as SiO ₂)	mg/L	IN	30	19.3	24.1	22.1	1.0
	mg/L	AO	30	19.6	24.3	22.2	0.9
	mg/L	TA	19	21.0	23.1	22.0	0.6
	mg/L	TB	15	20.4	23.2	21.9	0.7
	mg/L	TC	15	20.6	23.1	22.1	0.7
	mg/L	TD	15	20.5	23.2	22.1	0.7
	mg/L	TT	11	19.5	30.4	24.8	4.0
Turbidity	NTU	IN	30	14.0	40.0	32.8	4.6
	NTU	AO	30	6.5	14.0	10.1	1.6
	NTU	TA	19	0.3	8.0	2.5	2.4
	NTU	TB	15	0.2	8.6	1.5	2.0
	NTU	TC	15	0.3	2.5	0.9	0.6
	NTU	TD	15	0.1	2.7	1.1	0.8
	NTU	TT	11	0.2	5.5	2.0	1.8

Table 4-13. Summary of Other Water Quality Parameter Results (Continued)

Parameter	Unit	Sample Location	Sample Count	Concentration			Standard Deviation
				Minimum	Maximum	Average	
Total Organic Carbon (TOC)	mg/L	IN	15	5.8	8.9	7.9	0.8
	mg/L	AO	15	6.8	8.5	7.7	0.5
	mg/L	TA	4	7.2	8.8	7.9	0.7
	mg/L	TT	11	6.7	7.9	7.4	0.4
pH	S.U.	IN	10 ^(d)	6.9	8.0	7.3	0.4
	S.U.	AO	11 ^(e)	7.2	8.2	7.5	0.3
	S.U.	TA	4	7.4	7.5	7.4	0.1
	S.U.	TT	8 ^(f)	6.7	8.2	7.6	0.5
Temperature	°C	IN	13	12.7	15.0	14.3	0.7
	°C	AO	13	13.3	15.8	14.4	0.8
	°C	TA	4	14.4	16.0	15.2	0.7
	°C	TT	9	13.3	19.4	14.8	1.9
Dissolved Oxygen (DO)	mg/L	IN	13 ^(g)	0.6	2.5	1.2	0.6
	mg/L	AO	14	1.1	3.4	1.6	0.6
	mg/L	TA	4	1.2	1.6	1.3	0.2
	mg/L	TT	10	0.6	2.1	0.9	0.5
Oxidation Reduction Potential (ORP)	mV	IN	9 ^(h)	-71.6	41.7	-31.0	34.8
	mV	AO	13	207	487	392	76.6
	mV	TA	4	34.4	180	102	62.7
	mV	TT	9 ^(f)	30.9	754	392	254
Total Hardness (as CaCO ₃)	mg/L	IN	15	318	601	476	71.7
	mg/L	AO	15	277	551	469	63.3
	mg/L	TA	4	269	473	400	91.8
	mg/L	TT	11	432	548	478	35.3
Ca Hardness (as CaCO ₃)	mg/L	IN	15	104	325	244	53.1
	mg/L	AO	15	104	302	244	49.5
	mg/L	TA	4	106	275	210	74.6
	mg/L	TT	11	193	294	251	32.1
Mg Hardness (as CaCO ₃)	mg/L	IN	15	170	308	232	29.0
	mg/L	AO	15	174	279	224	22.0
	mg/L	TA	4	163	204	190	18.2
	mg/L	TT	11	194	276	228	21.0

(a) One outlier each on 01/25/10, 02/24/10, 03/23/10, 06/15/10, and 07/14/10 not included in calculations.

(b) One outlier on 06/30/10 not included in calculations.

(c) One outlier each on 09/15/09, 01/25/10, 02/24/10, 03/23/10, 06/15/10, and 07/14/10 not included in calculations.

(d) One outlier each on 09/15/09, 10/15/09, and 05/19/10 not included in calculations.

(e) One outlier each on 10/15/09 and 05/19/10 not included in calculations.

(f) One outlier on 10/15/09 not included in calculations.

(g) One outlier on 05/19/10 not included in calculations.

(h) One outlier each on 11/11/09, 01/25/10, 02/24/10, 03/23/10, 07/14/10 not included in calculations.

Arsenic and Iron Removal. Two of the most critical parameters for evaluating the effectiveness of the C/F system were arsenic and iron concentrations in the treated water. Figure 4-14 presents three bar charts showing results of the 15 speciation events at the IN, AO, and TT (or TA) sampling locations. On April 22, May 19, August 18, and September 15, 2010, speciation samples of treated water were collected from the TA sampling location because of cross contamination by post-treatment chemicals at the TT location. This was not unexpected because the post-treatment chemical addition injection points were located only less than 2 ft downgradient of the TT location. Results of the speciation samples collected at AO on August 19 and September 15, 2009, were not included in the statistical analysis because the

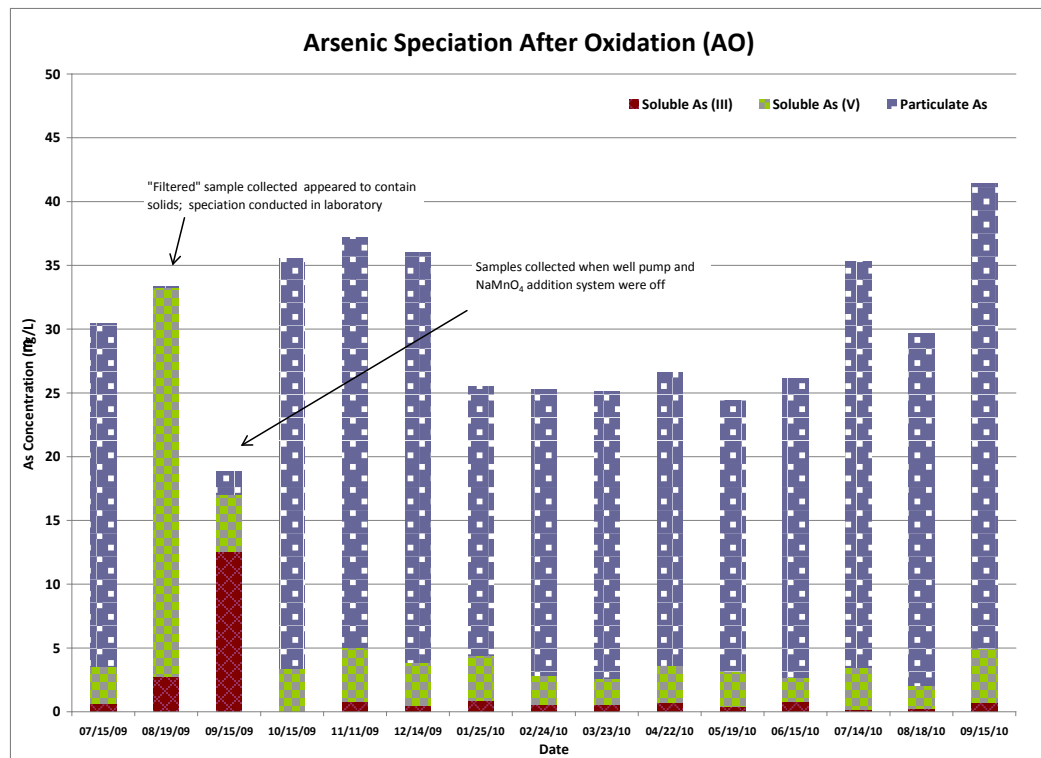
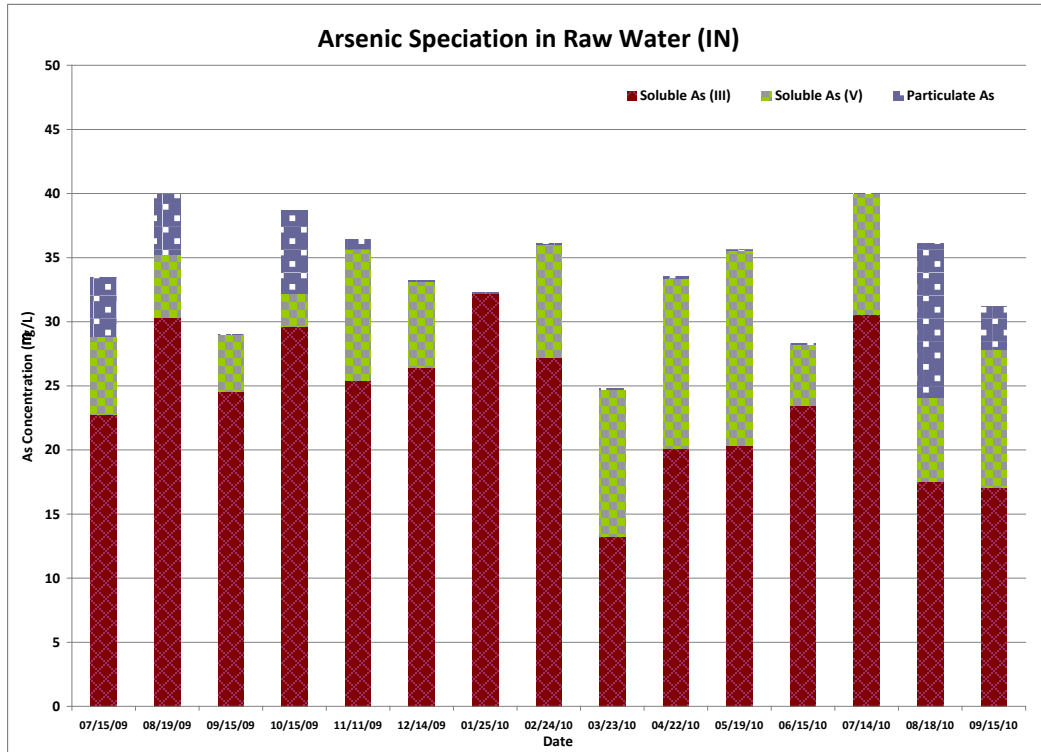


Figure 4-14. Arsenic Speciation at Sampling Locations IN, AO, and TT (or TA)

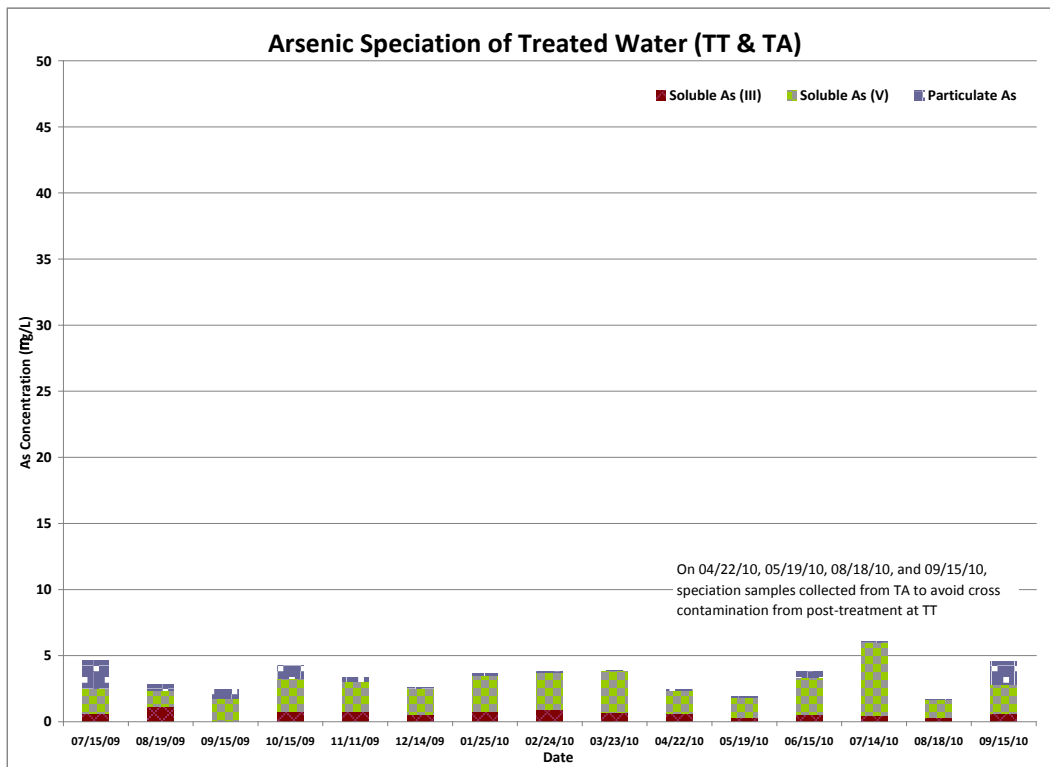


Figure 4-14. Arsenic Speciation at Sampling Locations IN, AO, and TT (or TA) (Continued)

August 19 sample was not properly collected and because the September 15 sample was collected when the system was not in operation.

Total arsenic concentrations in raw water ranged from 23.9 to 45.2 µg/L and averaged 33.1 µg/L, existing almost entirely as soluble arsenic (see Table 4-12). Of the soluble fraction, As(III) was the predominating species with concentrations ranging from 13.3 to 32.2 µg/L and averaging 24.1 µg/L. Soluble As(V) concentrations were lower, ranging from <0.1 to 15.2 µg/L and averaging 7.7 µg/L. Particulate arsenic concentrations also were low, ranging from <0.1 to 12.0 µg/L and averaging 2.2 µg/L. The arsenic concentrations obtained during the performance evaluation study were consistent with those collected previously during source water sampling conducted by Battelle (see Table 4-1).

Total iron concentrations in raw water ranged from 1,939 to 2,720 µg/L and averaged 2,298 µg/L, existing almost entirely as soluble iron. The presence of predominating soluble iron was consistent with the presence of predominating soluble As(III) as well as low DO and ORP levels (i.e., 1.2 mg/L and -31 mV, respectively [on average]). The -31 mV average ORP value does not include five uncharacteristically high readings (that range from 282 to 386 mV) measured on November 11, 2009, and January 25, February 24, March 23, and July 14, 2010. Omitting these values was based on the belief that these values were erroneous because soluble As(III) remained the predominating arsenic species in the same samples. While it was not clear what had caused the high ORP readings, one contributing factor was the Symphony SP90M5 Handheld Multimeter, which, from time to time, tended to drift over the course of measurements. Similar problems were encountered at several arsenic demonstration sites as reported previously by Chen et al. (2010a).

Given the average soluble iron and soluble arsenic levels in source water, this corresponded to an iron to arsenic ratio of 72:1, which was well above the target ratio of 20:1 for effective arsenic removal by iron removal (Sorg, 2002). As shown in Table 4-12 and Figure 4-15, total iron concentrations varied in a relatively wide range from 1,939 to 2,720 µg/L. Varying iron concentrations could affect KMnO₄ dosage, which was critical to the formation of filterable manganese solids, as discussed later in this subsection.

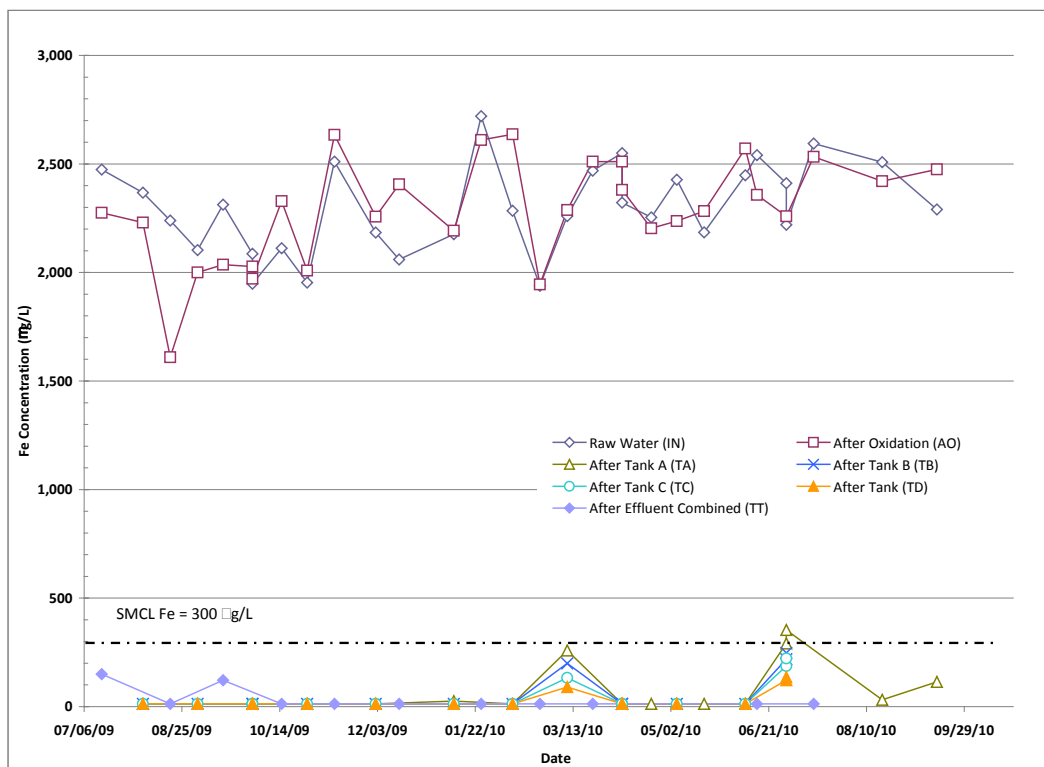


Figure 4-15. Total Iron Concentrations Across Treatment Train

Following NaMnO₄ addition at the AO sampling location, total arsenic concentrations remained essentially unchanged, ranging from 18.9 to 43.2 µg/L and averaging 31.3 µg/L. Oxidation of soluble As(III) converted arsenic almost entirely to particulate arsenic (with concentrations ranging from 21.1 to 36.4 µg/L and averaging 27.1 µg/L), presumably via adsorption and/or co-precipitation of soluble As(V) with iron solids. A small fraction (at 11.2%) of arsenic remained in the soluble form, existing as both As(III) and As(V) at 0.6 and 3.0 µg/L (on average), respectively. These, along with the jar test results, clearly demonstrate that NaMnO₄ is effective in oxidizing soluble As(III) and that most soluble As(V) formed can get attached to iron particles also produced during the oxidation process. Removal of arsenic would now be determined if these arsenic-laden particles can be filtered by the downstream GreensandPlus™ filters.

Unlike what was observed at most other arsenic demonstration sites, addition of an oxidant (i.e., NaMnO₄ in this case) to water from Wells No. 6 and No. 8 did not completely oxidize soluble Fe(II) to iron solids. As shown in Table 4-12, soluble iron at Sampling Location AO ranged from <25 to 147 µg/L and averaged 48.1 µg/L. Out of the 13 sets of speciation samples (excluding two on August 19 and September 15, 2009 for reasons shown in the second bar chart of Figure 4-14), three contained 107 to 147 µg/L of soluble iron. A study has shown that soluble Fe(II) that complexes with DOM can be difficult to

treat via oxidation and subsequent precipitation. This was due to the formation of colloidal particles with a size fraction smaller than 0.2- μm filters. Colloid formation, however, may be affected by factors such as DOM concentration and types (Knocke et al., 1994). The “incomplete” iron oxidation observed at Waynesville, IL might have been the artifact from the formation of colloidal particles promoted by the presence of significantly elevated (7.9 mg/L) TOC in source water (Table 4-13). Colloidal iron formed might have penetrated through 0.45- μm filters and then was analyzed as soluble iron.

The results in Table 4-12 show that total arsenic concentrations after the GreensandPlus™ filters were reduced to <4.6 $\mu\text{g/L}$, indicating effective removal of arsenic-laden particles by the filters. Particulate arsenic concentrations were reduced from 27.1 $\mu\text{g/L}$ (on average) after oxidation to 0.5 $\mu\text{g/L}$ (on average) after filtration, representing greater than 98% arsenic removal. As expected, the small amount of soluble As(III) (i.e., 0.6 $\mu\text{g/L}$ [on average]) left after oxidation remained in the filtered effluent. Some soluble As(V) after oxidation appeared to have been further removed as the pre-oxidized water was processed by the filters. Figure 4-16 plots total arsenic concentrations across the treatment train at Sampling Locations IN, AO, TA, TB, TC, TD, and TT.

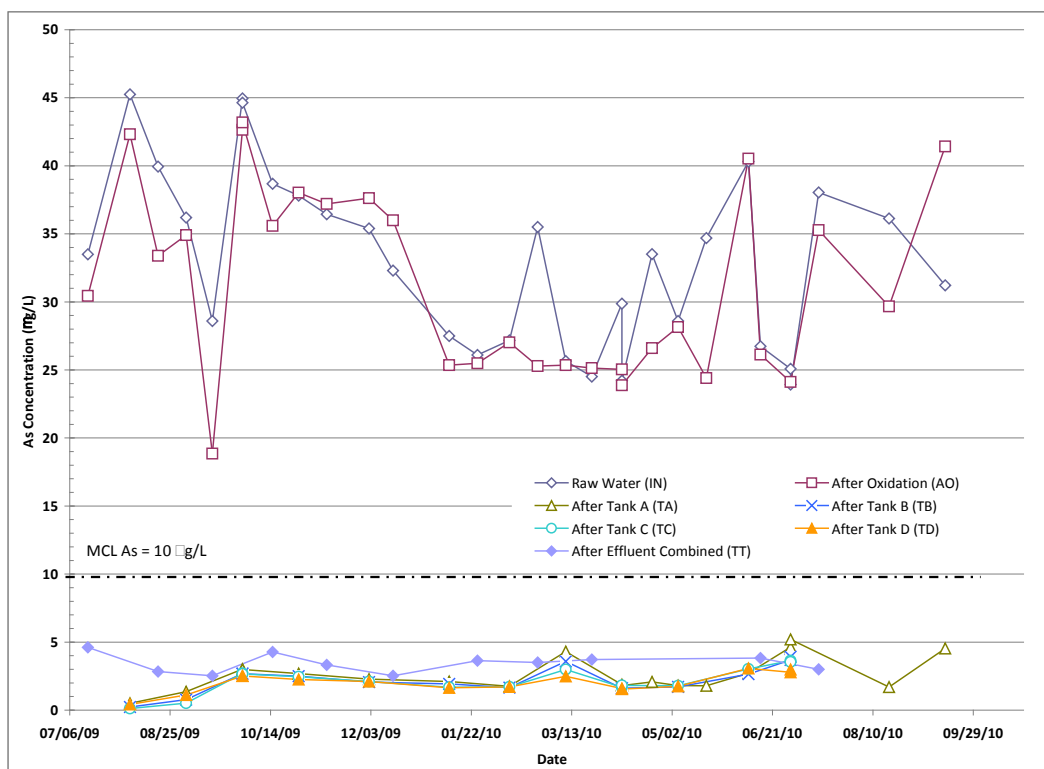


Figure 4-16. Total Arsenic Concentrations Across Treatment Train

The GreensandPlus™ filters effectively removed arsenic-laden iron particles, reducing the average total iron concentration to 34.9 $\mu\text{g/L}$ in the combined filter effluent. As shown in Figure 4-15 and Appendix B, iron concentrations in the filter effluent were reduced to below the MDL of 25 $\mu\text{g/L}$ on 25 out of 30 sampling occasions, including the three occasions that had over 100 $\mu\text{g/L}$ of “soluble” iron in oxidized water. Prior studies have revealed that prolonged contact times can result in more complete oxidation of soluble iron (Vikesland and Valentine, 2002), thus reducing its concentrations after the filters. Of the other five occasions, one on September 15, 2009, contained 86 $\mu\text{g/L}$ (existing entirely as particulate iron);

one on March 10, 2010 contained 90 to 259 $\mu\text{g/L}$ (no speciation data); two (including one duplicate event) on June 30, 2010, contained 121 to 353 $\mu\text{g/L}$ (no speciation data); and one on September 15, 2010, contained 678 $\mu\text{g/L}$ (with 114 $\mu\text{g/L}$ existing as soluble iron). Elevated iron concentrations in the filter effluent could be due to the combination of particulate and colloidal iron particle breakthrough, although there was no evidence to support accompanying particulate arsenic breakthrough under the circumstances.

A few pieces of data that should not be ignored are DO concentrations across the treatment train (see Table 4-13). As discussed earlier, DO concentrations in raw water averaged 1.2 mg/L. After NaMnO_4 addition and GreensandPlus™ filtration, DO concentrations remained relatively unchanged at 1.6 and 1.3 mg/L, respectively (on average). To maintain this rather reducing condition, it is imperative to keep the source water from being exposed to air because incidental contact with air can cause unwanted iron precipitation and media fouling due to microbial activities (such as nitrification). It is well known that pre-formed iron is not as effective in removing soluble As(V) from aqueous solution (Hering et al., 1996) and that air can be utilized by nitrifying bacteria such as *Nitrosomonas* and *Nitrobacter* to convert ammonia to nitrate. At another arsenic demonstration site at Arnaudville, LA, where source water also contained mostly soluble As(III) and elevated TOC and ammonia (at 1.3 and 1.9 mg/L [as N], respectively), more than 10 $\mu\text{g/L}$ of soluble As(V) was measured in KMnO_4 -oxidized water even though the soluble iron to soluble arsenic ratio was 65:1 (Chen et al., 2011b). Further, two downstream pressure filters containing an engineered ceramic filter media were severely fouled due to extensive microbial activities. It was discovered that incidental aeration in a supposedly refurbished, air-tight contact tank had caused the problems observed and that bypassing the contact tank (or discontinuing air contact) had helped reduce soluble As(V) concentrations after KMnO_4 addition.

In summary, GreensandPlus™ filtration is effective in removing arsenic-laden particles at a filtration rate of less than 3.4 gpm/ft² (see Table 4-7). The pre-set backwash schedule of once every three days as discussed in Section 4.4.2 appears to be adequate to restore the filters and allow them to perform in a sustainable manner. Iron leakage from the filters, however, can be an issue, which warrants the operator's occasional attention (such as performing spot checks for total iron using a field Hach meter) during system operation. The feedback from homeowners throughout the Village indicates that once the treatment system was put online, the water from their taps was consistently clear and “rust rings” in their toilets gradually decreased and disappeared.

Manganese. Total manganese concentrations in raw water ranged from 21.2 to 108 $\mu\text{g/L}$ and averaged 33.1 $\mu\text{g/L}$, existing almost entirely in the soluble form. After NaMnO_4 addition (AO), total manganese concentrations increased, as expected, to levels ranging from 1,331 to 3,981 $\mu\text{g/L}$ and averaging 2,451 $\mu\text{g/L}$ (or 6.4 mg/L [as NaMnO_4]). This value reflects an average NaMnO_4 dosage of approximately 6.3 mg/L (as NaMnO_4) (less the amount already in raw water), which is close to the measured dose rate of 6.9 mg/L (NaMnO_4) as discussed in Section 4.4.3 and plotted in Figure 4-17. A significant amount of manganese (ranging from 26.4 to 1567 $\mu\text{g/L}$ and averaging 765 $\mu\text{g/L}$) remained in the soluble form, which might exist as soluble Mn(II) (due to the formation of Mn(II)-DOM complexes [Gregory and Carlson, 2003]), KMnO_4 (due to overdosing), or colloidal MnO_2 particles (due to the presence of DOM [Shiao et al., 2009]).

Soluble Mn(II) oxidation by KMnO_4 is dependent on the KMnO_4 dosage, pH, temperature, and DOM concentration in raw water. The reaction between KMnO_4 with soluble Mn(II) is typically rapid and complete at pH values ranging from 5.5 to 9.0. However, elevated DOM levels can increase the KMnO_4 demand due to competition between these species and resulting kinetic effects (Knocke et al., 1987). Some researchers suggest that DOM can interfere with the formation of MnO_2 solids by exerting KMnO_4 demand and, possibly, forming complexes with soluble Mn(II), thus rendering it less likely to be oxidized (Gregory and Carlson, 2003). When modeling soluble Mn(II) oxidation with KMnO_4 , Carlson and

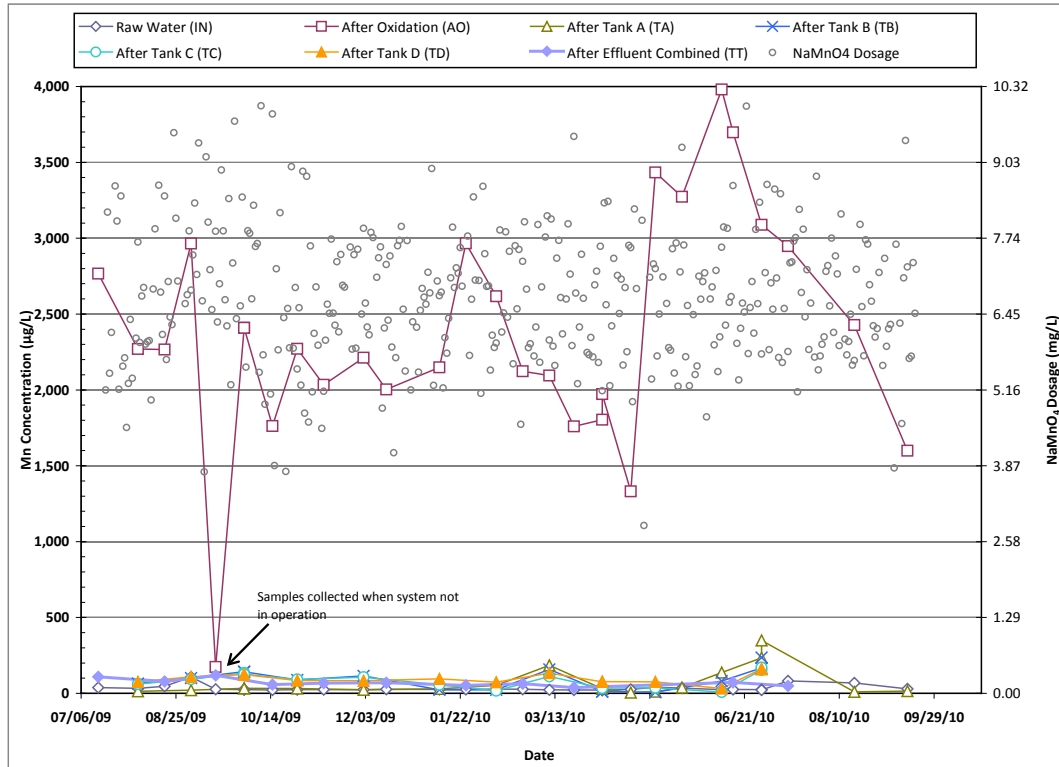


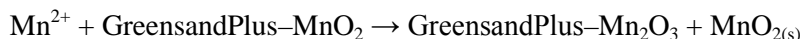
Figure 4-17. Total Manganese Concentrations Across Treatment Train

Knocke (1999) determined that incorporating a term to account for the DOM demand for MnO_4^- significantly improved the prediction of the MnO_4^- consumption. The incorporation of DOM into the oxidation term to account for complexation between DOM and Mn(II) also was postulated, but no data were collected as part of that study.

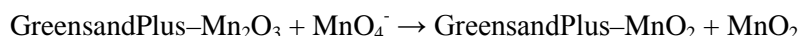
High levels of DOM in source water can form fine colloidal MnO_2 particles, which may not be filterable by conventional gravity or pressure filters. At Big Sauk Lake Mobile Home Park in Minnesota, significantly elevated “soluble” manganese levels (e.g., 1,097 $\mu\text{g/L}$ with the use of 0.45 μm filters) were detected after KMnO_4 addition, even though the level of KMnO_4 addition was less than the theoretical demand of 3.3 mg/L (as KMnO_4) for reduced species in source water (Shiao et al., 2009). Increasing the KMnO_4 dosage to 4.5 mg/L during a series of jar tests reduced soluble manganese concentrations to 0.8 $\mu\text{g/L}$. Similar soluble manganese concentration reductions (to as low as 35 $\mu\text{g/L}$ [on average]) also were observed at the treatment plant when the KMnO_4 dosage was increased to 4.4 to 5.8 mg/L (as KMnO_4). It was therefore concluded that in the presence of elevated DOM, KMnO_4 will react with reducing species in raw water to form colloidal particles and that increasing the KMnO_4 dosage can help offset the DOM effect and form filterable MnO_2 particles. Knocke et al. (1991) defined colloidal particles as those passing through 0.20- μm filters and requiring ultrafiltration for removal.

After the GreensandPlus™ filters, total manganese concentrations were reduced significantly to <100 $\mu\text{g/L}$ (on average). Manganese existed mostly as particulate manganese, indicating leakage of MnO_2 particles through the filters. As discussed in Section 4.5.2, the use of NaMnO_4 as an oxidant will increase loading to the filters and shorten useful filter run lengths. The filters were backwashed once every three days, which was capable of maintaining sustainable filter runs for arsenic and iron removal,

but not enough to consistently reduce manganese concentrations to below the 50-µg/L SMCL. Soluble manganese concentrations were reduced to less than 55 µg/L in the combined effluent, suggesting that the 6.3 mg/L of NaMnO₄ added not only oxidized reducing species, but also helped overcome the TOC effect as desired. The extra contact time from the addition point through the GreensandPlus™ filters seemed to be needed to allow particles to form. One advantage of using Greensand and MnO₂-related filtration media is the media's abilities to react with any soluble Mn(II) still in the water. A possible reaction pathway is shown below:



The reduced surface (GreensandPlus-Mn₂O₃) would then be re-oxidized when in contact with KMnO₄:



It is not clear if the “soluble” manganese measured actually existed as Mn(II) or colloidal MnO₂ particles.

Ammonia and TOC. Source water contained high levels of ammonia, averaging 3.8 mg/L (as N). As expected, ammonia did not react with NaMnO₄, as reflected by its essentially unchanged concentrations across the treatment train. This, along with below the MDL of nitrate across the treatment train, confirmed that nitrification did not occur throughout the demonstration period.

TOC concentrations in source water also were high, ranging from 5.8 to 8.9 mg/L and averaging 7.9 mg/L. Some TOC concentration reductions were observed after NaMnO₄ addition and across the GreensandPlus™ filters, as have been reported in the literature (EPA, 1999).

Competing Anions. As discussed in Section 4.1.1, phosphorus and silica could compete with arsenic for available adsorption sites on iron solids. Phosphorus concentrations in raw water ranged from 27.2 to 141 µg/L and averaged 89.1 µg/L. After GreensandPlus™ filtration, phosphorus concentrations were significantly reduced to below 14.8 µg/L (on average). Silica concentrations in raw water ranged from 19.3 to 24.1 mg/L (as SiO₂) and averaged 22.1 mg/L (as SiO₂). Its concentrations remained essentially unchanged across the treatment train. Therefore, their effect on arsenic removal should be minimal.

Other Water Quality Parameters. As shown in Table 4-13, alkalinity levels in raw water ranged from 542 to 651 mg/L (as CaCO₃) and averaged 599 mg/L (as CaCO₃). Alkalinity levels remained essentially unchanged across the treatment train. pH values of raw water ranged from 6.9 to 8.0 and averaged 7.3. pH values increased slightly (with a maximum increase of 0.3 pH unit [on average]) following GreensandPlus™ filtration. Fluoride and sulfate concentrations in raw water were low and remained relatively constant across the treatment train.

4.6.2 Backwash Wastewater and Solids Sampling. Table 4-14 summarizes analytical results from the 12 backwash wastewater sampling events. Total arsenic, iron, and manganese concentrations in backwash wastewater collected during all 12 backwash events ranged from 2.7 to 2,105 µg/L, 20,300 to 348,354 µg/L, and 1,284 to 157,725 µg/L, respectively; the respective average concentrations were 432, 86,432, and 46,572 µg/L. As expected, arsenic, iron, and manganese existed mainly in the particulate form. TSS levels ranged from 105 to 1,710 mg/L and averaged 441 mg/L. The wide variations observed in these measurements were attributed, in part, to difficulties in collecting representative samples containing suspended solids. Based on 441 mg/L of TSS and 3,100 gal of wastewater production (see Section 4.4.2), approximately 11.4 lb (or 5,175 g) of solids would be discharged to the septic systems and then to the sewer. The solids would contain 0.01 lb (or 5.0 g) of arsenic, 2.2 lb (or 1,014 g) of iron, and 1.2 lb (or 547 g) of manganese.

Table 4-14. Backwash Wastewater Sampling Results

		Vessel A										Vessel B									
		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	07/15/09	7.3	592	550	788	3.1	785	89,670	<25	58,715	12.3	7.3	562	185	303	3.3	300	21,144	<25	15,271	13.0
2	08/19/09	7.3	530	450	858	6.8	851	89,144	342	61,509	261	7.4	582	255	659	8.6	651	71,600	439	47,015	344
3	09/15/09	7.4	560	490	392	3.8	388	90,161	35	58,171	34.5	7.3	588	350	474	3.8	470	59,413	36	49,128	31.4
4	10/15/09	7.3	524	940	530	4.4	526	151,804	141	83,635	108	7.4	500	780	561	4.4	556	128,547	74	72,264	56.0
5	11/11/09	7.4	494	1,390	1,953	3.1	1,950	309,198	35	134,933	27.6	7.3	554	1,250	1,839	3.7	1,835	278,801	102	129,158	77.8
6	12/14/09	7.5	516	560	1,230	4.7	1,225	142,445	<25	73,061	31.5	7.4	552	400	1,272	3.1	1,269	136,449	34	70,230	27.3
7	01/25/10 ^(a)	7.4	518	345	10.4	2.5	8.0	75,233	77	47,689	57.2	7.3	530	355	2.7	2.5	0.2	<25 ^(a)	85	1,284	65.3
8	02/24/10	7.4	518	215	13.5	2.5	11.1	37,745	62	13,334	51.5	7.3	518	375	16.2	1.8	14.3	31,566	<25	12,043	18.9
9	03/23/10	7.5	470	105	29.5	2.1	27.4	45,946	25	26,796	25.6	7.5	502	245	9.8	2.4	7.4	57,198	68	39,986	41.8
10	04/22/10	7.6	542	460	14.2	2.2	12.0	68,515	26	19,240	24.9	7.4	528	210	14.8	2.0	12.8	45,905	<25	14,296	18.8
11	05/19/10	7.3	548	310	16.9	1.9	15.0	32,206	<25	17,744	13.2	7.5	536	170	17.0	1.8	15.2	27,466	<25	15,616	19.6
12	06/15/10	7.5	534	245	17.0	2.5	14.4	62,840	<25	43,222	14.1	7.4	518	270	17.1	2.4	14.7	62,979	<25	44,966	14.6
Minimum		7.3	470	105	10.4	1.9	8.0	32,206	<25	13,334	12.3	7.3	500	170	2.7	1.8	0.2	21,144	12.5	1,284	13.0
Maximum		7.6	592	1,390	1,953	6.8	1,950	309,198	342	134,933	261	7.5	588	1,250	1,839	8.6	1,835	278,801	439	129,158	344
Average		7.4	528	505	488	3.3	485	99,576	66.1	53,171	55.1	7.4	539	404	432	3.3	429	83,734	75.1	42,605	60.7
Minimum (Overall)		7.3	464	105	2.7	1.8	0.2	20,300	<25	1,284	12.3										
Maximum (Overall)		8.0	702	1,710	2,105	155	2,102	348,354	439	157,725	344										
Average (Overall)		7.4	528	441	432	6.3	426	86,432	59.1	46,572	49.2										

(a) Considered outlier and not included for calculations.

Table 4-14. Backwash Wastewater Sampling Results (Continued)

		Vessel C										Vessel D									
		pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)	pH	TDS	TSS	As (total)	As (soluble)	As (particulate)	Fe (total)	Fe (soluble)	Mn (total)	Mn (soluble)
No.	Date	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	S.U.	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
1	07/15/09	7.4	540	290	499	3.0	496	46,837	<25	31,769	13.0	7.3	516	280	378	3.0	375	23,749	<25	16,539	14.4
2	08/19/09	7.3	520	335	611	3.7	607	66,124	40	44,405	37.1	7.4	528	325	622	4.8	617	62,639	119	40,187	86.7
3	09/15/09	7.3	534	380	457	4.1	453	60,796	56	47,789	50.0	7.3	540	320	450	4.6	445	57,120	40	46,742	47.2
4	10/15/09	7.4	512	940	501	3.9	497	163,145	52	84,924	43.5	7.4	504	600	371	155	216	126,173	58	64,843	26.4
5	11/11/09	7.3	504	840	1,411	3.6	1,408	193,964	93	88,629	70.5	7.3	512	1,710	2,105	3.0	2,102	348,354	<25	157,724	28.8
6	12/14/09	7.4	486	580	1,190	3.6	1,186	131,256	63	68,538	47.1	7.5	516	380	904	3.5	900	102,095	51	55,666	40.6
7	01/25/10 ^(a)	7.3	492	150	24.5	3.8	20.7	39,103	212	28,491	141	7.5	510	315	13.0	2.0	10.9	62,910	32	46,448	27.9
8	02/24/10	7.3	498	185	15.1	2.4	12.7	36,611	60	12,686	52.9	7.3	702	305	15.2	2.0	13.2	20,300	27	9,750	25.3
9	03/23/10	7.5	464	290	19.6	2.1	17.4	52,142	32	34,960	27.5	8.0	502	300	16.9	2.5	14.4	59,691	71	37,804	50.6
10	04/22/10	7.4	514	310	9.3	2.1	7.2	39,146	<25	24,934	31.2	7.5	528	350	11.6	2.1	9.5	47,745	<25	15,341	27.9
11	05/19/10	7.5	534	270	14.9	2.1	12.8	41,348	<25	20,169	19.9	7.4	512	320	14.9	2.1	12.8	48,911	35	23,728	32.0
12	06/15/10	7.4	530	225	22.7	2.2	20.5	56,247	<25	40,791	12.3	7.5	520	275	19.2	2.4	16.9	59,917	<25	43,300	20.0
Minimum		7.3	464	150	9.3	2.1	7.2	36,611	<25	12,686	12.3	7.3	502	275	11.6	2.0	9.5	20,300	<25	9,750	14.4
Maximum		7.5	540	940	1,411	4.1	1,408	193,964	212	88,629	141	8.0	702	1,710	2,105	155	2,102	348,354	119	157,725	86.7
Average		7.4	511	400	398	3.1	395	77,227	54.9	44,007	45.5	7.5	533	457	410	15.6	395	84,967	40.2	46,506	35.6

Table 4-15 presents total metal results of the backwash solid samples collected from the four filtration vessels. Arsenic, iron, and manganese levels averaged 1,546 (or 0.15%), 152,707 (or 15.3%), and 109,514 µg/g (or 11.0%), respectively. Based on 5,175 g of solids produced, 7.8 g of arsenic, 792 g of iron, and 569 g of manganese would exist, which are rather comparable to the amounts (i.e., 5.0, 1,014, and 547 g) as calculated above.

4.6.3 Distribution System Water Sampling. Table 4-16 presents results of six baseline and 14 monthly distribution system water sampling events. Table 4-17 summarizes the average and range of the stagnation time and each of the 11 analytes. In addition to the analytes commonly measured for all other arsenic demonstration projects, ammonia, nitrate, nitrite, and TOC also were analyzed due to the presence of significantly elevated ammonia and TOC levels in Wells No. 6 and No. 8 water. Ammonia concentrations in the distribution system water after system startup ranged from 3.3 to 4.8 mg/L (as N) and averaged 3.8 mg/L, almost identical to the levels measured in the source water and filter effluent. This, along with the below MDL levels of nitrate and nitrite, suggest that nitrification did not occur in the distribution system. Before system startup, ammonia concentrations averaged 3.9 and 3.5 mg/L (as N) at Residences 1 and 3, respectively. However, ammonia concentrations at Residence 2 were uncharacteristically low at 0.9 and 0.5 mg/L [as N]. It was not clear what had caused the low concentrations observed. TOC concentrations in the distribution system water were similar, averaging 7.6 and 7.4 mg/L before and after system startup. These concentrations were about the same as those in the filter effluent, but somewhat lower than those in source water.

Comparison of arsenic, iron, and manganese levels at three residences before system startup indicated significant differences, with Residence 3 having the highest arsenic and iron levels (at 36.9 and 2,244 µg/L, respectively), followed by Residence 2 (at 20.0 and 500 µg/L, respectively) and Residence 1 (13.2 and 187 µg/L, respectively). CMT Engineering confirmed that among the three residences, Residence 1 is located the most downgradient of the distribution network (or the farthest from the treatment plant). It was possible that arsenic-laden particles formed upon chlorination at the wellhead gradually settled in the distribution system, resulting in progressively lower arsenic and iron concentrations along the length of the distribution system. Similar observations were made at the Town of Seville, Ohio, during its spring fire hydrant flush as part of a separate EPA arsenic task order conducted by Battelle in early 2000.

Following system startup, total arsenic concentrations were significantly reduced to 11.8, 6.8, and 7.7 µg/L (on average) at Residences 1, 2, and 3, respectively. However, out of the 42 samples collected, 14 samples contained more than 10 µg/L of arsenic, including 10 samples collected in the months immediately following system startup (see the exceedances in Table 4-16). Excluding these exceedances, arsenic concentrations at Residence 2 essentially mirrored the concentrations in the filter effluent. Arsenic concentrations at Residences 1 and 3, however, were generally higher than those in the treatment plant effluent. After system startup, iron concentrations were significantly reduced to 41.0, 55.3, and 345 µg/L (on average) at Residences 1, 2, and 3, respectively. The 345-µg/L average concentration at Residence 3 was much higher than those in the filter effluent.

The higher arsenic and iron concentrations measured in distribution system water suggest solubilization, destabilization, and/or desorption of arsenic-laden particles/scales in some segments of the distribution system. Similar observation were made by other researchers (Lytle and Sorg, 2005) and at a number of arsenic demonstration sites including LEADS Head Start Building in Buckeye Lake, OH (Chen et al., 2011a), the Town of Felton, DE (Chen et al., 2010a), the City of Sabin, MN (Chen et al., 2010b), Spring Brook Mobile Home Park in Wales, ME (Lipps et al. 2010), Terry Trojan Water District in Lead, SD (Wang et al., 2010a), Upper Bodfish in Lake Isabella, CA (Wang et al., 2010b), Oak Manor Municipal Utility District in Alvin, TX (Wang et al., 2010c), Richmond Elementary School in Susanville, CA (Chen et al., 2009a), Vintage on the Ponds in Delavan, WI (Chen et al., 2009b), the City of Stewart, MN (Condit

Table 4-15. ICP-MS Results of Backwash Solids Samples

Sample ID	Metals													
	Mg	Al	Si	P	Ca	Fe	Mn	Ni	Cu	Zn	As	Cd	Ba	Pb
	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
Vessel A – 1	11,294	709	7557	3,548	41,501	92,840	67,997	4.4	32.8	437	941	<15	2,806	6.2
Vessel A – 2	11,873	546	8521	3,732	39,928	86,687	62,209	4.6	35.0	459	955	<15	2,746	8.4
Average	11,583	628	8,039	3,640	40,714	89,764	65,103	4.5	33.9	448	948	<15	2,776	7.3
Vessel B – 1	36,942	2,429	28,586	8,455	141,973	196,631	133,033	20.3	183	944	1,998	<15	5,921	29.8
Vessel B – 2	39,752	2,530	26,246	9,176	140,376	215,715	158,775	24.3	373	1,079	2,139	<15	6,569	35.8
Average	38,347	2,480	27,416	8,816	141,174	206,173	145,904	22.3	278	1,011	2,069	<15	6,245	32.8
Vessel C – 1	30,474	1,223	14,832	6,728	100,210	155,939	112,161	12.1	66.8	668	1,560	<15	4,619	15.4
Vessel C – 2	28,879	1,504	14,547	6,372	962,96	149,776	108,073	11.4	65.2	635	1,519	<15	4,372	13.9
Average	29,676	1,363	14,689	6,550	982,53	152,858	110,117	11.8	66.0	652	1,539	<15	4,495	14.7
Vessel D – 1	21,814	1,545	16,615	6,536	88,958	161,367	116,895	15.4	195	841	1,601	<15	4,870	25.6
Vessel D - 2	22,633	1,189	16,375	6,725	90,075	162,694	116,967	13.0	172	1,515	1,656	<15	4,998	25.2
Average	22,223	1,367	16,495	6,630	89,516	162,031	116,931	14.2	184	1,178	1,629	<15	4,934	25.4

Table 4-16. Distribution Sampling Results

No.	Sampling Date	Analytes										Pb	Cu
		Stagnation Time	pH	Alkalinity	Ammonia (as N)	Nitrate (as N)	Nitrite (as N)	TOC (mg/L)	As	Fe	Mn		
		Hrs	S.U.	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Residence 1													
BL1	03/09/09	11.0	7.8	578	NA	NA	NA	NA	15.7	86	21.1	<0.1	1,145
BL2	03/30/09	11.3	7.4	593	NA	NA	NA	NA	11.1	804	1.7	<0.1	846
BL3	04/13/09	11.8	7.9	596	NA	NA	NA	NA	13.4	36	19.5	<0.1	882
BL4	04/22/09	9.0	7.4	599	NA	NA	NA	NA	13.6	71	20.0	<0.1	905
BL5	05/06/09	NA	7.5	630	3.9	<0.05	NA	7.8	13.3	60	21.3	0.1	1,290
BL6	05/13/09	11.0	7.7	617	3.9	<0.05	NA	7.4	11.9	66	21.7	<0.1	1,427
1	08/05/09	11.5	7.3	581	3.8	<0.05	NA	7.9	18.6	<25	17.2	<0.1	907
2	09/02/09	11.5	7.3	570	3.4	<0.05	NA	7.3	17.1	<25	31.8	<0.1	801
3	09/30/09	12.0	7.6	555	3.7	<0.05	NA	6.6	17.8	<25	42.5	<0.1	783
4	10/28/09	12.0	7.3	552	3.7	<0.05	NA	6.8	11.7	<25	51.3	<0.1	477
5	12/02/09	12.5	7.4	578	3.8	<0.05	<0.05	6.7	10.4	<25	55.1	0.1	715
6	01/11/10	11.8	7.8	638	3.6	<0.05	<0.05	6.8	9.4	<25	54.9	<0.1	766
7	02/10/10	11.8	7.9	631	3.7	<0.05	<0.05	7.4	9.0	45	70.2	<0.1	843
8	03/10/10	12.3	7.7	626	3.9	<0.05	<0.05	7.5	7.3	28	71.5	<0.1	804
9	04/07/10	13.0	7.4	591	3.8	<0.05	<0.05	8.3	6.8	<25	75.1	0.2	1,153
10	05/05/10	12.6	7.8	617	4.0	<0.05	<0.05	7.5	7.6	<25	69.8	<0.1	878
11	06/09/10	11.3	7.4	608	4.2	<0.05	<0.05	7.5	13.1	<25	76.6	<0.1	1,024
12	06/30/10	13.5	7.3	599	4.0	<0.05	<0.05	7.9	14.1	<25	67.0	<0.1	364
13	08/18/10	10.5	7.4	629	3.9	<0.05	<0.05	5.8	7.5	51	64.6	<0.1	817
14	09/15/10	12.5	7.3	609	4.2	<0.05	<0.05	8.0	14.5	<25	65.9	<0.1	564
Residence 2													
BL1	03/09/09	7.8	7.5	605	NA	NA	NA	NA	15.8	89	20.9	<0.1	1,211
BL2	03/30/09	6.5	7.5	604	NA	NA	NA	NA	33.6	1,238	3.9	2.0	300
BL3	04/13/09	6.9	7.5	601	NA	NA	NA	NA	17.6	217	1.2	0.8	359
BL4	04/22/09	7.2	7.5	606	NA	NA	NA	NA	17.0	303	1.3	0.9	431
BL5	05/06/09	NA	7.5	628	0.9	<0.05	NA	8.2	15.6	379	1.3	0.8	420
BL6	05/13/09	8.0	7.6	617	0.5	<0.05	NA	7.5	20.3	774	2.9	1.2	465
1	08/05/09	6.6	7.4	574	0.3	<0.05	NA	7.8	15.6	47	3.5	0.3	314
2	09/02/09	7.1	7.4	565	3.3	<0.05	NA	7.9	13.3	70	1.9	0.4	235
3	09/30/09	6.8	7.5	573	3.6	<0.05	NA	6.5	12.5	59	2.4	0.4	293
4	10/28/09	6.8	7.2	546	0.5	<0.05	NA	7.1	5.2	27	1.4	0.3	162
5	12/02/09	6.5	7.5	589	3.7	<0.05	<0.05	6.5	3.7	26	1.8	0.5	268
6	01/11/10	6.5	7.6	636	3.7	<0.05	<0.05	6.6	4.0	123	64.1	1.0	375
7	02/10/10	7.0	7.5	638	3.8	<0.05	<0.05	7.5	3.4	50	25.8	0.7	471
8	03/10/10	7.3	7.6	600	4.8	<0.05	<0.05	7.7	2.9	26	24.0	0.7	343
9	04/07/10	6.5	7.6	604	3.8	<0.05	<0.05	8.0	4.0	92	70.5	1.4	477
10	05/05/10	6.4	7.5	617	4.0	<0.05	<0.05	7.6	3.7	34	24.7	0.8	402
11	06/09/10	6.0	7.5	592	3.9	<0.05	<0.05	7.6	7.0	27	18.0	0.6	408
12	06/30/10	6.5	7.6	684	3.9	<0.05	<0.05	7.8	4.8	35	19.5	0.6	314
13	08/18/10	6.1	7.5	613	3.8	<0.05	<0.05	7.3	5.0	86	41.0	0.9	292
14	09/15/10	6.8	7.4	661	3.9	<0.05	<0.05	8.0	10.0	72	70.1	1.3	305
Residence 3													
BL1	03/09/09	8.3	7.6	594	NA	NA	NA	NA	13.9	141	19.8	0.2	405
BL2	03/30/09	7.5	7.6	602	NA	NA	NA	NA	72.2	4,063	23.3	4.4	553
BL3	04/13/09	8.0	7.8	612	NA	NA	NA	NA	40.4	3,067	22.0	11.7	549
BL4	04/22/09	8.0	8.1	599	NA	NA	NA	NA	38.9	2,553	21.5	12.1	493
BL5	05/06/09	NA	7.6	606	3.5	<0.05	NA	7.1	34.4	2,740	23.0	5.4	577
BL6	05/13/09	7.5	7.6	607	3.5	<0.05	NA	7.5	21.8	901	23.4	0.3	67.4
1	08/05/09	10.5	7.3	570	3.7	<0.05	NA	7.9	8.8	<25	33.4	<0.1	160
2	09/02/09	7.0	7.5	570	3.4	<0.05	NA	7.5	12.2	61	60.6	<0.1	128
3	09/30/09	8.0	7.6	570	3.5	<0.05	NA	6.6	12.4	87	72.6	0.2	293
4	10/28/09	9.0	7.5	561	3.7	<0.05	NA	7.0	5.7	31	78.2	<0.1	192
5	12/02/09	7.5	7.5	580	3.6	<0.05	<0.05	6.6	5.5	121	78.8	0.3	265
6	01/11/10	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
7	02/10/10	8.4	7.9	635	3.7	<0.05	<0.05	7.7	7.0	700	197	3.3	448
8	03/10/10	8.0	8.0	596	3.8	<0.05	<0.05	7.6	5.9	200	112	0.5	291
9	04/07/10	7.5	7.7	604	3.7	<0.05	<0.05	8.0	6.0	626	182	3.3	462
10	05/05/10	7.0	7.7	620	3.9	<0.05	<0.05	7.9	5.6	620	162	3.5	333
11	06/09/10	7.8	7.8	598	4.0	<0.05	<0.05	7.6	10.9	564	154	3.7	348
12	06/30/10	8.0	7.4	599	3.8	<0.05	<0.05	8.2	5.4	374	89.6	1.1	286
13	08/18/10	7.0	7.4	626	3.9	<0.05	<0.05	8.8	5.3	411	85.5	3.9	295
14	09/15/10	6.5	7.4	647	3.7	<0.05	<0.05	8.0	9.7	<25	162	0.6	308

Note: Pb action level = 15 µg/L; Cu action level = 1,300 µg/L

Table 4-17. Summary of Distribution System Water Sampling Results

Analytes	Unit	Type of Measurements	Average (Range)
Stagnation Time	hr	Baseline	8.6 (6.5–11.8)
		Actual	8.9 (6.0–13.5)
pH	S.U.	Baseline	7.6 (7.4–8.1)
		Actual	7.5 (7.2–8.0)
Alkalinity (as CaCO ₃)	mg/L	Baseline	605 (758–630)
		Actual	601 (546–684)
Ammonia (as N)	mg/L	Baseline	2.7 (0.5–3.9)
		Actual ^(a)	3.8 (3.3–4.8)
Nitrate (as N)	mg/L	Baseline	<0.05
		Actual	<0.05
Nitrite (as N)	mg/L	Baseline	NA
		Actual	<0.05
TOC	mg/L	Baseline	7.6 (7.1–8.2)
		Actual	7.4 (5.8–8.8)
As (total)	µg/L	Baseline	23.4 (11.1–72.2)
		Actual	8.8 (2.9–18.6)
Fe (total)	µg/L	Baseline	977 (35.7–4,063)
		Actual	168 (25.7–700)
Mn (total)	µg/L	Baseline	15.0 (1.2–23.4)
		Actual	64.6 (1.4–197.3)
Pb (total)	µg/L	Baseline	3.3 (0.1–12.1)
		Actual	1.2 (0.1–3.9)
Cu (total)	µg/L	Baseline	685 (67.4–1,427)
		Actual	472 (128–1,153)

(a) Not including two outliers on 08/05/09 and 10/28/09.

et al., 2009), White Rock Water Company Water System in Bow, NH (McCall et al., 2008), and the City of Climax in MN (Condit and Chen, 2006).

Manganese concentrations measured after system startup averaged 58.1, 26.3, and 112.9 µg/L at Residences 1, 2, and 3, respectively; these concentrations were higher than those measured before system startup, but lower than those (except for Residence 3) in the filter effluent. It is not clear why manganese concentrations decreased in the distribution system, but manganese particles can deposit on scales within the distribution system especially with the added contact time.

Lead concentrations remained constant and averaged 3.3 and 1.2 µg/L before and after system startup, respectively. Copper concentrations decreased slightly from 685 µg/L before system startup to 472 µg/L after system startup. One baseline sample collected from Residence 1 on May 13, 2009, exceeded the copper action level at 1,427 µg/L. Factors such as low pH, high temperature, and soft water with lower dissolved minerals can increase the solubility of copper in drinking water when in contact with plumbing fixtures. What had caused the one elevated copper concentration is unknown.

4.7 System Cost

The treatment system cost was evaluated based on the capital cost per gpm (or gpd) of the design capacity and the O&M cost per 1,000 gal of water treated. The capital cost of the treatment system includes the

cost for equipment, site engineering, and system installation. The O&M cost includes the cost for chemicals, electricity, and labor. All costs associated with construction of the new water treatment facility and post-treatment chemical addition systems were not included in the capital cost because neither were included in the scope of the demonstration study and because these costs were funded separately by the Village of Waynesville.

4.7.1 Capital Cost. The total capital investment for equipment, site engineering, and installation of the Peerless C/F system was \$161,559 (see Table 4-18). The equipment cost was \$90,749 (or 56.2% of the total capital investment), which included \$24,200 for the four filtration vessels, \$5,726 for the media (including #1 anthracite, GreensandPlus™, and gravel underbedding), \$27,326 for process valves and piping, \$9,996 for instrumentation and controls, \$7,956 for four additional flow meters/totalizers on the four vessels, \$2,545 for the NaMnO₄ addition system, \$4,500 for shipping, and \$8,500 for labor.

Table 4-18. Capital Investment Cost for Peerless GreensandPlus™ System

Description	Quantity	Cost	% of Capital Investment
<i>Equipment Cost</i>			
Filtration Vessels	4	\$24,200	—
#1 Anthracite	7 ft ³ /vessel	\$424	—
GreensandPlus Media	14 ft ³ /vessel	\$4,757	—
Support Gravel	13 ft ³ /vessel	\$545	—
Process Valves & Piping	—	\$27,326	—
Instrumentation and Controls	—	\$9,996	—
Additional Flowmeter/Totalizers	4	\$7,956	—
NaMnO ₄ Addition System	1	\$2,545	—
Shipping	—	\$4,500	—
Labor	—	\$8,500	—
Equipment Total	—	\$90,749	56.2%
<i>Engineering Cost</i>			
Subcontractor Material	—	\$240	—
Subcontractor Labor	—	\$21,630	—
Subcontractor Travel	—	\$590	—
Engineering Total	—	\$22,460	13.9%
<i>Installation Cost</i>			
Subcontractor Material	—	\$13,818	—
Subcontractor Labor	—	\$34,532	—
Installation Total	—	\$48,350	29.9%
Total Capital Investment	—	\$161,559	100%

The site engineering cost included the cost for the preparation of system engineering plans and drawings for piping tie-ins, electrical requirements for system components, tank fill details, and system layout and footprint to assist in facility construction, as well as submission of a permit application package to IL EPA for approval. The site engineering cost was \$22,460, or 13.9% of the total capital investment. Site engineering was performed by CMT Engineering of Springfield, IL.

The installation cost included the material and labor to unload and install the four filtration vessels, perform piping tie-ins and electrical work, load and backwash the media, and perform system shakedown and startup. The installation cost was \$48,350 (or 29.9% of the total capital investment). System

installation was performed by G.A. Rich & Sons, Inc. of Deer Creek, IL in coordination with CMT Engineering.

The total capital cost of \$161,559 was normalized to the system's rated capacity of 96 gpm (or 138,240 gpd), which results in \$1,683/gpm (or \$1.17 gpd) of design capacity. The capital cost also was converted to an annualized cost of \$15,250/yr using a capital recovery factor of 0.09439 based on a 7% interest rate and a 20-yr return period. Assuming that the system operated 24 hr/day, 7 day/week at the design flowrate of 96 gpm to produce 50,457,600 gal/yr, the unit capital cost would be \$0.30/1,000 gal. During the demonstration period from July 15, 2009 through September 19, 2010, the system produced 12,603,800 gal of water or 10,649,000 gal/year. At this reduced rate of usage, the unit capital cost increased to \$1.43/1,000 gal.

4.7.2 Operation and Maintenance Cost. The total O&M cost for items including chemical usage, electricity consumption, and operator labor was \$0.68/1,000 gal of water treated (see Table 4-19). The total chemical cost for NaMnO₄ addition during the demonstration period was \$5,976 or \$0.47/1,000 gal of water treated. Electrical consumption was calculated based on the difference between the cost from utility bills before and after system startup. The monthly difference in electrical consumption was \$67.20 or \$0.08/1,000 gal of water treated. Under normal operating conditions, routine labor activities to operate and maintain the system consumed 0.25 hr/day with 7 visits per week. The total labor cost for routine labor activities during the demonstration period was \$1,620 or \$0.13/1,000 gal of water treated.

Table 4-19. Operation and Maintenance Cost for Peerless GreensandPlus™ System

Cost Category	Value	Assumptions
Volume Processed (gal)	12,603,800	During 432-day study period, equivalent to 10,649,000 gal/yr
<i>Chemical Usage</i>		
20.0% NaMnO ₄ Unit Cost (\$/gal)	13.43	445 gal ordered during study period
NaMnO ₄ Consumption (gal/1,000 gal)	0.035	
Chemical Cost (\$/1,000 gal)	0.47	
<i>Electricity Consumption</i>		
Electricity Cost (\$/month)	67.20	Approximate incremental electricity consumption after system startup
Electricity Cost (\$/1,000 gal)	0.08	
<i>Labor Cost</i>		
Average Labor (hr/day)	0.25	7 visits/week
Labor Through Study Period (hr)	108	During 432-day study period
Labor Cost through Study Period (\$)	1,620	At \$15.00/hr during study period
Labor Cost (\$/1,000 gal)	0.13	–
<i>Total O&M Cost (\$/1,000 gal)</i>	0.68	For chemical usage, electricity consumption, and labor

5.0 REFERENCES

- Amy, G.L., P.A. Chadik, and P.H. King. 1984. "Chlorine Utilization During Trihalomethane Formation in the Presence of Ammonia and Bromide." *Environ. Sci. Technol.*, 18:781-786.
- Battelle. 2009. *System Performance Evaluation Study Plan: U.S. EPA Demonstration of Arsenic Removal Technology Round 2a at Village of Waynesville, IL.*. Prepared under Contract No.EP-C-05-057. Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Battelle. 2007. *Quality Assurance Project Plan for Evaluation of Arsenic Removal Technology (QAPP ID 355-Q-6-0)*. Prepared under Contract No.EP-C-05-057, Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Bougard, C.M.M., E.H. Goslan, B. Jefferson, and S.A. Parsons. 2010. "Comparison of the Disinfection By-product Formation Potential of Treated Waters Exposed to Chlorine and Monochloramine," *Water Research*, 44: 729-740.
- Carlson, Kenneth H., and William R. Knocke. 1999. "Modeling Manganese Oxidation with KMnO_4 for Drinking Water Treatment." *JAWWA* 125(10): 892-896.
- Carus Corporation. 2001. Determination of Cairax® Potassium Permanganate Residual for Drinking Water Applications: DPD Spectrophotometric Method. Analytical Method 103.
- Chen, A.S.C., J.P. Lipps, R.J. Stowe, B.J. Yates, V. Lal, and L. Wang. 2011a. *Arsenic Removal from Drinking Water by Adsorptive Media, U.S. EPA Demonstration Project at LEADS Head Start Building in Buckeye Lake, OH, Final Performance Evaluation Report*. EPA/600/R-11/002. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., W.E. Condit, B.J. Yates, and L. Wang. 2011b. *Arsenic Removal from Drinking Water by Coagulation/Filtration, U.S. EPA Demonstration Project at Town of Arnaudville, LA, Final Performance Evaluation Report*. Prepared under Contract No.EP-C-05-057, Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., R.J. Stowe, and L. Wang. 2011c. *Arsenic Removal from Drinking Water by Coagulation/Filtration, U.S. EPA Demonstration Project at Conneaut Lake Park in Conneaut Lake, PA, Final Performance Evaluation Report*. Prepared under Contract No.EP-C-05-057, Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., G.M. Lewis, L. Wang, and A. Wang. 2010a. *Arsenic Removal from Drinking Water by Coagulation/Filtration, U.S. EPA Demonstration Project at Town of Felton, DE, Final Performance Evaluation Report*. EPA/600/R-10/039. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., W.E. Condit, B.J. Yates, and L. Wang. 2010b. *Arsenic Removal from Drinking Water by Iron Removal. U.S. EPA Demonstration Project at Sabin, MN. Final Performance Evaluation*

- Report*. EPA/600/R-10/033. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., J.P. Lipps, S.E. McCall, and L. Wang. 2009a. *Arsenic Removal from Drinking Water by Adsorptive Media. U.S. EPA Demonstration Project at Richmond Elementary School in Susanville, CA. Final Performance Evaluation Report*. EPA/600/R-09/067. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., L. Wang, and W.E. Condit. 2009b. *Arsenic Removal from Drinking Water by Iron Removal, U.S. EPA Demonstration Project at Vintage on the Ponds in Delavan, WI, Final Performance Evaluation Report*. EPA/600/R-09/066. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Chen, A.S.C., L. Wang, J. Oxenham, and W. Condit. 2004. *Capital Costs of Arsenic Removal Technologies: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-04/201. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Condit, W.E., A.S.C. Chen, L. Wang, and A. Wang. 2009. *Arsenic Removal from Drinking Water by Iron Removal and Adsorptive Media, U.S. EPA Demonstration Project at Stewart, MN, Final Performance Evaluation Report*. EPA/600/R-09/144. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Condit, W.E. and A.S.C. Chen. 2006. *Arsenic Removal from Drinking Water by Iron Removal, U.S. EPA Demonstration Project at Climax, MN, Final Performance Evaluation Report*. EPA/600/R-06/152. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Edwards, M., S. Patel, L. McNeill, H.-W. Chen, M. Frey, A.D. Eaton, R.C. Antweiler, and H.E. Taylor. 1998. "Considerations in Arsenic Analysis and Speciation." *Journal AWWA*, 90(3):103-113.
- EPA. 2003. "Minor Clarification of the National Primary Drinking Water Regulation for Arsenic." *Federal Register*, 40 CFR Part 141.
- EPA. 2002. *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*. EPA/816/R-02/009. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 2001. National Primary Drinking Water Regulations: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. *Federal Register*, 40 CFR Parts 9, 141, and 142.
- EPA. 1999. *Alternative Disinfectants and Oxidants Guidance Manual*. EPA/815/R-99/014. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.
- EPA. 1998. National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts; Final Rule. 40 CFR Parts 9, 141 and 142.
- Ficek, K.J. 1994. *The Potassium Permanganate/Greensand Process for Water Treatment*. Presented at 20th Annual WQA Convention, Phoenix, AZ, March 14.

- Frank, P.L. and D.A. Clifford. 1986. *Arsenic (III) Oxidation and Removal from Drinking Water*. EPA/600/S2-86/021. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Gregory, D., and K. Carlson. 2003. "Effect of Soluble Mn Concentration on Oxidation Kinetics ." *JAWWA* 95(1): 98-108.
- Ghurye, G.. and D. Clifford. 2001. *Laboratory Study on the Oxidation of Arsenic III to Arsenic V*. EPA/600/R-01/021. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Hering, J.G., P.Y. Chen, J.A. Wilkie, E. Menachem, and L. Sun. 1996. "Arsenic Removal by Ferric Chloride." *JAWWA*, 88(4):155.
- Knocke, W.R., Hoehn, R.C., Sinsabaugh, R.L. 1987. Using Alternative Oxidants to Remove Dissolved Manganese From Waters Laden With Organics. *J. AWWA*, 79(3): 75-79.
- Knocke, William R., Holly L. Shorney, and Julia D. Bellamy. 1994. "Examining the Reactions Between Soluble Iron, DOC, and Alternative Oxidants During Conventional Treatment." *JAWWA* 86(1): 117-127.
- Knocke, W.R., Van Benschoten, J.E., Kearney, M., Soborski, A., and Reckhow, D.A. 1990. *Alternative Oxidants for the Remove of Soluble Iron and Manganese*. Final report prepared for the AWWA Research Foundation, Denver, CO.
- Lipps, J.P., A.S.C. Chen, L. Wang, A. Wang, and S.E. McCall. 2010. *Arsenic Removal from Drinking Water by Adsorptive Media. U.S. EPA Demonstration Project at Spring Brook Mobile Home Park in Wales, ME. Final Performance Evaluation Report*. EPA/600/R-10/012. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Lytle D.A. and T.J. Sorg. 2005. "Distribution System Issues." Presented at the Workshop on Arsenic Removal from Drinking Water – August 16 to 18, Cincinnati, OH.
- Magyar, J. 1992. Personal Communication, Kelliher Arsenic Removal Study Saskatchewan Environment and Public Safety, Regina, Canada. November 4.
- McCall, S.E., A.S.C. Chen, and L. Wang. 2008. *Arsenic Removal from Drinking Water by Adsorptive Media. U.S. EPA Demonstration Project at Bow, NH. Final Performance Evaluation Report*. EPA/600/R-08/006. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Pedersen III, E. J. 2001. Greensand Filtration Removes Radium. *Water Technology*, August: 51-55.
- Rathbun, R.E. 1997. "Effect of Reaction Time on the Formation of Disinfection Byproducts." *Chemosphere*. 34(12): 2699-2713.
- Shiao, H.T., A.S.C. Chen, L. Wang, and W.E. Condit. 2009. *Arsenic Removal from Drinking Water by Iron Removal, U.S. EPA Demonstration Project at Big Sauk Lake Mobile Home Park in Sauk Centre, MN, Final Performance Evaluation Report*. EPA/600/R-09/013. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

- Sorg, T.J. 2002. "Iron Treatment for Arsenic Removal Neglected." *Opflow*, AWWA, 28(11): 15.
- Summers, R.S., S.M. Hooper, H.M. Shukairy, G. Solarik, and D. Owen. 1996. "Assessing DBP Yield: Uniform Formation Conditions," *J. AWWA*. 88: 80-93.
- Sun, Y-X., Q-Y. Wu, H-Y Hu, J. Tian, J. 2009. "Effect of Ammonia on the Formation of THMs and HAAs in Secondary Effluent Chlorination." *Chemosphere*, 76:631-637.
- Vikesland, P.J. and R.L. Valentine. 2002. "Modeling the Kinetics of Ferrous Iron Oxidation by Monochloramine." *Environ. Sci. and Technol.* 36(4):662-668.
- Valigore, J.M., A.S.C. Chen, W.E. Condit, and L. Wang. 2008. *Arsenic Removal from Drinking Water by Iron Removal, U.S. EPA Demonstration Project at City of Sandusky, MI, Final Performance Evaluation Report*. EPA/600/R-08/007. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang, L., A.S.C. Chen, V. Lal, and L.J. Cumming. 2011. *Arsenic Removal from Drinking Water by Solid Oxidizing Media and Adsorptive Media, U.S. EPA Demonstration Project at Hot Springs Mobile Home Park in Willard, UT, Final Performance Evaluation Report*. Prepared under Contract No. EP-C-05-057. Task Order No. 0019, for U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang A, A.S.C. Chen, and L. Wang. 2010a. *Arsenic Removal from Drinking Water by Adsorptive Media. U.S. EPA Demonstration Project at Lead, SD. Final Performance Evaluation Report*. EPA/600/R-10/179. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang, L., A.S.C. Chen, and G.M. Lewis. 2010b. *Arsenic and Uranium Removal from Drinking Water by Adsorptive Media. U.S. EPA Demonstration Project at Upper Bodfish in Lake Isabella, CA. Final Performance Evaluation Report*. EPA/600/R-10/165. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang, L., A.S.C. Chen, and A. Wang. 2010c. *Arsenic Removal from Drinking Water by Adsorptive Media. U.S. EPA Demonstration Project at Oak Manor Municipal Utility District at Alvin, TX. Final Performance Evaluation Report*. EPA/600/R-10/045. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.
- Wang, L., W.E. Condit, and A.S.C. Chen. 2004. *Technology Selection and System Design: U.S. EPA Arsenic Removal Technology Demonstration Program Round 1*. EPA/600/R-05/001. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH.

APPENDIX A

OPERATIONAL DATA

Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ^(a) (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
1	07/15/09	11:37		NA		21.3	0	10	20.6	0	1	20.7	0	3	21.6	0	3	YES	0	17.00	NA
	07/16/09	16:23		NA		11.4	9,940	6	11.6	10,050	0	12.4	10,440	0	11.8	9,740	0	NO	44,705	16.25	NA
	07/17/09	16:15	45.56	NA		11.5	17,530	7	11.5	17,750	1	12.3	18,610	1	12.1	17,670	0	NO	50,505	16.00	NA
	07/18/09	16:20	44.50	102,160			28,050	5		28,270	2		29,500	1		27,800	2	NO	58,590	15.00	NA
	07/19/09	16:00	42.40	131,960	30,220	10.8	35,800	6	10.9	28,400	0	11.5	37,740	0	11.2	35,760	0	NO	58,590	14.25	5.2
2	07/20/09	16:00		169,540	37,580	10.9	46,360	5	10.6	45,740	2	11.1	48,640	2	11.5	45,960	2	YES	61,650	12.75	8.2
	07/21/09	16:00	41.20	197,790	28,250	10.9	53,760	6	11.2	54,340	0	11.7	56,580	1	11.3	48,430	1	NO	61,650	12.00	5.4
	07/22/09	16:00	42.25	222,840	25,050	11.5	59,620	5	11.1	60,940	2	10.9	63,570	1	11.1	60,210	2	NO	61,650	11.25	6.1
	07/23/09	16:00	41.40	258,490	35,650	10.5	68,940	5	10.7	69,890	2	10.6	72,780	1	10.9	68,890	2	YES	64,710	25.00	NA
	07/24/09	16:00	40.00	294,130	35,640	10.6	79,270	5	11.1	80,470	2	10.5	83,880	1	10.1	79,240	2	NO	64,710	23.50	8.6
3	07/25/09	19:30	43.22	332,420	33,417	11.1	89,320	9	11.2	90,650	2	11.6	94,500	2	11.0	89,460	2	NO	64,710	22.00	8.0
	07/26/09	16:30	36.78	362,150	33,977	9.3	97,810	5	9.7	99,190	1	10.1	103,190	1	9.1	97,300	1	YES	67,760	21.25	5.2
	07/27/09	16:10	44.00	392,450	30,727	21.5	105,560	4	20.5	107,250	1	20.5	111,650	2	22.0	105,350	2	NO	67,760	20.00	8.5
	07/28/09	15:50	43.00	420,090	28,029	10.5	112,800	4	10.5	109,520	1	10.9	119,100	2	10.3	112,690	1	NO	67,760	19.25	5.6
	07/29/09	15:00		465,010	46,536	20.5	125,590	6	21.0	127,120	2	20.0	131,880	2	20.5	124,970	2	YES	70,810	18.00	5.7
4	07/30/09	16:12	42.70	487,680	21,590	10.7	131,160	5	11.2	133,000	0	12.0	138,310	0	11.8	131,440	0	NO	70,810	17.50	4.5
	07/31/09	16:28	41.00	516,860	28,859	10.7	138,600	7	11.0	140,700	0	11.5	146,510	1	10.9	139,390	0	NO	70,810	16.75	5.3
	08/01/09	16:06	37.90	549,110	32,750	10.7	147,760	5	10.4	149,960	1	10.9	156,010	1	9.3	147,860	1	YES	73,850	15.75	6.4
	08/02/09	16:16		577,810	28,502		155,300	4		157,660	1		164,080	1		155,310	2	NO	73,850	15.00	5.4
	08/03/09	17:05	41.20	607,410	28,626	11.0	163,150	8	11.0	165,560	1	11.3	172,290	1	11.0	163,280	1	NO	73,850	24.00	NA
5	08/04/09	16:20	37.70	641,360	35,045	10.1	172,900	5	10.9	175,310	1	10.6	182,270	1	9.2	172,640	2	YES	76,890	23.00	6.0
	08/05/09	16:22	41.60	668,070	26,673	10.9	179,840	6	11.1	182,340	0	11.6	189,620	0	11.2	179,440	0	NO	76,890	22.00	7.7
	08/06/09	16:15	37.40	702,430	34,528	9.8	188,840	7	9.8	191,400	1	10.3	199,110	1	10.2	188,720	0	NO	76,890	21.00	6.0
	08/07/09	16:15		732,780	30,350		197,590	5		200,050	2		207,920	1		196,820	2	YES	79,950	20.00	6.8
	08/08/09	16:15		762,480	29,700		205,470	5		208,070	1		216,200	1		204,570	1	NO	79,950	19.00	6.9
6	08/09/09	16:23	42.50	788,370	25,747	11.4	212,400	7	11.2	215,000	0	11.4	223,320	1	11.2	211,500	1	NO	79,950	18.25	5.9
	08/10/09	16:15	37.30	822,650	34,472	10.2	222,210	6	10.4	224,740	1	10.7	233,210	1	9.1	220,730	1	YES	83,010	17.25	6.0
	08/11/09	16:25	41.70	848,280	25,453	11.1	229,090	6	11.1	231,630	0	11.6	240,400	0	11.1	227,330	0	NO	83,010	16.50	6.0
	08/12/09	15:40	37.70	879,100	31,814	10.1	237,290	7	10.0	239,770	1	10.4	248,910	1	10.1	235,620	1	NO	83,010	15.75	5.0
	08/13/09	14:50	36.40	908,920	30,893	9.8	245,970	5	10.2	248,270	1	10.5	257,550	2	8.7	243,570	2	YES	86,060	14.75	6.9
7	08/14/09	16:35	45.20	934,870	24,186	11.6	252,910	6	11.5	255,360	0	11.9	264,860	0	11.5	250,250	0	NO	86,060	13.75	7.9
	08/15/09	16:40	37.00	968,160	33,175	10.1	261,820	7	9.9	264,250	1	10.1	273,990	1	9.7	259,080	0	NO	86,060	25.00	NA
	08/16/09	16:25	36.80	997,820	29,972	9.9	270,550	6	10.1	272,850	1	10.4	282,640	0	9.0	266,860	2	YES	89,110	23.75	8.6
	08/17/09	16:15	38.40	1,027,870	30,260	10.3	278,560	6	10.3	280,950	0	10.7	291,060	0	10.3	274,700	0	NO	89,110	22.75	6.8
	08/18/09	16:40	42.00	1,053,060	24,760	11.3	285,260	8	11.1	287,840	1	11.4	297,920	1	11.2	281,390	1	NO	89,110	22.00	6.1
8	08/19/09	17:40		1,083,360	29,088		294,190	5		296,340	2		306,620	1		289,400	2	YES	92,150	20.75	8.5
	08/20/09	16:40	41.60	1,110,440	28,257	11.1	301,440	7	11.2	303,740	0	11.4	314,220	0	11.0	296,320	0	NO	92,150	20.00	5.7
	08/21/09	16:25	38.20	1,139,720	29,588	10.9	307,410	6	10.8	311,840	1	11.2	322,590	1	11.0	304,020	1	NO	92,150	19.00	7.0
	08/22/09	16:20	36.30	1,171,750	32,142	9.8	318,690	5	10.0	320,820	1	10.2	331,500	1	8.8	312,480	1	YES	95,200	18.00	6.4
	08/23/09	16:00	34.80	1,204,450	33,161	9.5	327,520	6	9.5	329,660	0	9.8	340,610	0	9.3	321,010	NA	NO	95,200	17.00	6.3
9	08/24/09	16:20		1,236,700	31,808		336,310	5		338,360	1		349,530	1		329,510	2	NO	95,200	15.50	9.5
	08/25/09	16:50	32.90	1,274,770	37,293	8.4	347,470	5	9.3	349,340	1	9.5	360,480	1	7.8	339,270	1	YES	98,240	14.00	8.1
	08/26/09	16:15		1,304,010	29,968	21.3	355,620	13	20.9	350,270	1	21.0	368,570	1	21.0	346,780	0	NO	98,240	13.00	7.0
	08/27/09	16:45	39.90	1,337,070	32,385	10.3	364,200	11	10.9	366,060	0	10.9	377,440	0	10.7	355,630	1	NO	98,240	25.00	NA
	08/28/09	16:15		1,361,840	25,297		371,280	10		373,300	1		384,570	1		362,270	2	YES	101,280	23.50	12.4
10	08/29/09	17:00		1,390,850	28,131		NA	11		NA	0		NA	1		NA	0	NO	101,280	22.00	10.6
	08/30/09	16:10	36.10	1,421,790	32,053	9.8	NA	12	9.7	NA	1	10.0	NA	1	9.5	NA	1	NO	101,280	21.00	6.6
	08/31/09	16:22	45.30	1,452,040	30,000	11.8	379,940	3	12.0	381,930	1	11.9	393,300	0	10.9	370,480	1	YES	104,340	20.00	6.8
	09/01/09	16:50		1,478,110	25,573	21.3	381,110	5	21.7	389,200	1	22.0	400,650	2	21.5	377,230	1	NO	104,340	19.00	7.9
	09/02/09	16:00	39.50	1,508,010	30,976	10.4	394,880	7	10.5	397,110	2	11.0	408,790	1	10.4	385,000	3	NO	104,340	18.00	6.9
11	09/03/09	16:02	40.20	1,535,510	27,462	10.9	402,730	5	11.2	405,060	2	11.4	416,890	0	9.7	392,490	5	YES	107,400	17.00	7.5
	09/04/09	16:00	39.30	1,566,240	30,773	10.4	410,900	6	10.5	413,360	3	10.9	425,450	0	10.4	400,330	4	NO	107,400	15.75	8.3
	09/05/09	16:20	41.20	1,595,030	28,396	10.8	418,540	7	10.9	421,040	3	11.4	433,400	1	11.0	408,000	4	NO	107,400	14.75	7.1
	09/06/09	1																			

**Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet
(Continued)**

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ^(a) (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
11	09/20/09	15:30	40.80	2,032,970	32,793	10.5	539,370	4	10.7	541,600	4	11.0	552,770	1	10.8	522,570	4	NO	122,660	18.75	6.7
	09/21/09	17:40	42.60	2,065,790	30,102	11.8	548,780	3	11.5	550,870	3	11.5	565,030	0	10.2	531,200	0	YES	125,710	17.75	6.2
	09/22/09	16:30	43.90	2,090,160	25,615	11.5	555,630	5	11.2	557,520	4	11.4	571,760	1	11.0	537,370	2	NO	125,710	16.75	8.4
	09/23/09	16:05	40.80	2,119,460	29,818	10.9	563,480	3	10.9	565,190	1	11.2	579,600	1	10.7	544,880	0	NO	125,710	16.00	5.2
	09/24/09	17:16		2,147,480	26,703		571,690	1		573,260	1		587,690	1		552,180	3	YES	128,710	15.00	7.3
	09/25/09	15:46	42.40	2,173,820	28,096	11.2	578,830	2	11.3	580,410	3	11.5	594,930	0	11.0	558,770	3	NO	128,710	13.75	9.7
	09/26/09	15:50	37.60	2,206,000	32,091	10.4	587,560	4	10.0	588,950	3	10.3	603,680	1	9.7	567,180	2	NO	128,710	12.75	6.4
	09/27/09	16:16	37.50	2,236,730	30,185	10.4	594,830	2	10.4	597,780	1	10.5	612,550	0	9.0	575,150	3	YES	131,830	26.00	NA
12	09/28/09	16:05	37.30	2,267,840	31,349	10.1	604,890	3	9.9	606,250	3	10.2	621,200	0	9.9	583,220	3	NO	131,830	25.00	6.6
	09/29/09	16:05		2,292,130	24,290		611,480	1		619,870	2		627,780	1		589,580	4	NO	131,830	24.00	8.4
	09/30/09	16:00		2,321,420	29,392	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	YES	134,890	22.50	10.5
	10/01/09	16:00		2,349,140	27,720		627,720	1		628,630	1		643,850	2		604,130	5	NO	134,890	21.75	5.5
	10/02/09	16:20	42.00	2,375,200	25,703	11.3	634,820	4	11.1	635,630	4	11.4	650,960	2	11.1	611,010	3	NO	134,890	20.75	7.9
	10/03/09	16:20		2,407,960	32,760		644,360	2		644,940	1		660,290	1		619,530	5	YES	137,970	19.50	7.8
	10/04/09	16:05		2,438,520	30,882		652,720	1		653,300	1		668,750	1		627,270	5	NO	137,970	18.50	6.7
	10/05/09	16:12	41.10	2,463,220	24,581	11.0	659,400	3	11.0	659,920	4	11.1	675,480	1	10.7	633,750	2	NO	137,970	17.50	8.3
13	10/06/09	16:05		2,490,200	27,112		667,220	1		667,600	1		683,060	1		640,760	5	YES	141,050	16.50	7.6
	10/07/09	17:55	41.70	2,517,000	24,898	11.1	674,470	3	11.1	674,910	3	11.2	690,470	1	10.7	647,380	3	NO	141,050	15.50	7.6
	10/08/09	17:36	40.50	2,545,160	28,537	10.8	682,010	4	10.7	682,370	4	10.9	698,030	0	10.6	654,650	1	NO	141,050	14.75	5.5
	10/09/09	15:10		2,570,810	28,544		689,540	2		689,690	0		705,270	0		661,310	2	YES	144,120	13.50	10.0
	10/10/09	16:00	41.30	2,597,520	25,814	10.8	696,700	2	10.9	697,490	2	11.1	712,550	2	10.9	667,950	2	NO	144,120	12.75	5.8
	10/11/09	16:27	36.30	2,628,800	30,704	9.8	705,030	3	9.6	705,120	3	9.8	720,940	2	9.4	676,180	2	NO	144,120	12.00	4.9
	10/12/09	16:25	35.30	2,660,360	31,604	9.8	714,230	2	9.8	714,130	2	9.9	729,960	0	8.2	684,230	4	YES	147,170	12.50	NA
	10/13/09	16:30		2,681,000	20,569		719,800	3		719,640	3		735,560	0		689,360	2	NO	147,170	17.50	NA
14	10/14/09	18:30	40.60	2,711,220	27,895	10.8	727,890	4	10.7	727,590	4	10.9	743,670	1	10.6	697,220	1	NO	147,170	16.75	5.1
	10/15/09	15:00		2,737,230	30,451		735,550	1		735,000	1		751,080	1		704,000	1	YES	150,220	15.50	9.9
	10/16/09	16:35		2,763,690	24,822		742,680	1		742,150	2		758,260	0		710,450	2	NO	150,220	15.00	3.9
	10/17/09	16:10		2,792,080	28,892		750,350	2		749,660	2		763,890	1		717,720	2	NO	150,220	14.00	7.2
	10/18/09	16:38		2,827,190	34,440	20.2	760,580	3	20.4	759,640	3	20.7	775,870	0	19.1	726,590	3	YES	153,270	13.00	5.8
	10/19/09	16:55		2,852,270	24,787		767,300	1		766,300	1		782,630	0		732,830	4	NO	153,270	12.00	8.2
	10/20/09	17:45	41.80	2,878,750	25,591	11.1	774,410	5	11.0	773,300	5	11.1	789,750	1	10.7	739,670	0	NO	153,270	35.50	NA
	10/21/09	16:10		2,910,830	34,346		783,540	2		782,250	2		798,720	1		747,970	4	YES	156,340	34.50	6.4
15	10/22/09	16:10		2,938,000	27,170		790,870	1		789,550	1		806,190	1		754,670	4	NO	156,340	34.00	3.8
	10/23/09	16:30	43.20	2,969,320	30,891	11.4	799,340	3	11.1	797,800	4	11.3	814,630	2	10.9	762,780	1	NO	156,340	33.00	6.5
	10/24/09	16:00	35.60	3,004,210	35,632	9.9	809,510	1	10.0	807,700	1	10.1	824,470	0	8.1	771,570	4	YES	159,400	32.00	5.9
	10/25/09	16:20	35.40	3,038,540	33,860	9.7	818,730	2	9.4	816,860	3	9.6	833,780	1	9.1	780,320	1	NO	159,400	30.50	9.0
	10/26/09	16:55	40.50	3,064,740	25,578	10.9	825,900	4	10.6	823,790	4	10.8	840,810	2	10.3	787,000	0	NO	159,400	29.75	5.9
	10/27/09	16:00		3,094,450	30,890		834,690	1		832,210	1		849,140	1		794,490	3	YES	162,470	28.75	6.9
	10/28/09	17:45	41.60	3,122,320	25,976	11.1	842,250	2	11.0	839,720	4	11.1	856,720	1	10.5	801,330	3	NO	162,470	28.00	5.5
	10/29/09	16:10		3,145,770	25,106		848,560	1		845,870	2		862,940	0		807,270	4	NO	162,470	27.25	6.6
16	10/30/09	16:00		3,175,100	29,535		857,180	1		854,170	1		871,180	1		814,860	4	YES	165,550	26.50	5.2
	10/31/09	16:15		3,203,970	28,572		864,980	2		861,910	2		879,030	1		821,910	3	NO	165,550	25.25	8.9
	11/01/09	16:34	40.10	3,236,240	31,850	11.0	873,720	3	10.6	870,420	4	10.7	887,670	2	10.2	830,170	2	NO	165,550	24.50	4.8
	11/02/09	16:00	38.70	3,271,220	35,826	10.7	883,670	2	10.8	880,400	2	10.9	897,650	0	9.1	839,300	3	YES	168,620	23.00	8.8
	11/03/09	16:25		3,293,450	21,851		889,660	1		886,390	1		903,780	1		844,720	3	NO	168,620	22.50	4.6
	11/04/09	16:00		3,320,400	27,426		896,720	2		893,520	1		911,020	0		851,600	3	NO	168,620	21.50	7.6
	11/05/09	16:10		3,350,390	29,783		905,380	0		902,060	0		919,570	0		859,390	3	YES	171,690	20.75	5.1
	11/06/09	15:20	41.50	3,375,510	26,024	11.0	912,140	3	11.0	908,810	2	11.2	926,390	1	10.8	865,620	2	NO	171,690	20.00	6.1
17	11/07/09	15:15	40.80	3,405,180	29,773	11.1	920,100	3	10.9	916,620	3	10.9	934,320	2	10.5	873,310	0	NO	171,690	19.00	6.9
	11/08/09	16:25		3,439,810	33,025		930,180	1		926,390	1		944,050	0		882,290	2	YES	174,750	18.00	5.9
	11/09/09	16:00	41.70	3,467,500	28,179	11.2	937,640	2	11.0	933,740	2	11.2	951,500	1	10.6	889,250	2	NO	174,750	35.00	NA
	11/10/09	16:22		3,490,260	22,418		943,780	2		939,730	1		957,560	1		895,020	3	NO	174,750	34.50	4.5
	11/11/09	16:20		3,520,190	29,972		952,500	2		948,260	3		966,020	0		902,750	3	YES	177,800	33.75	5.1
	11/12/09	15:50	42.50	3,545,800	26,155	11.2	959,340	3	11.2	955,100	1	11.5	973,090	2	11.0	909,240	2	NO	177,800	33.00	6.0
	11/13/09	16:00		3,569,040	23,080		965,550	2		961,200	1		979,340	0		915,190	2	NO	177,800	32.25	

**Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet
(Continued)**

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ^(a) (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
21	11/28/09	15:30	40.30	3,977,450	31,440	11.1	1,078,870	4	10.7	1,072,780	4	10.8	1,091,870	3	10.0	1,018,130	0	NO	193,050	19.00	5.9
	11/29/09	16:20		4,004,600	26,239		1,086,900	1		1,080,590	1		1,099,530	0		1,025,000	2	YES	196,100	18.00	7.6
	11/30/09	16:25	42.60	4,033,280	28,581	11.4	1,094,690	2	11.2	1,088,300	2	11.4	1,107,300	1	10.4	1,031,950	2	NO	196,100	27.00	NA
	12/01/09	16:20		4,057,120	23,923		1,101,150	0		1,094,570	1		1,113,710	2		1,037,800	2	NO	196,100	26.25	6.4
	12/02/09	16:00		4,083,040	26,285		1,108,890	1		1,101,990	0		1,121,140	1		1,044,470	3	YES	199,150	25.25	7.9
	12/03/09	16:00		4,106,210	23,170		1,115,070	0		1,108,170	0		1,127,470	2		1,050,240	3	NO	199,150	24.50	6.6
	12/04/09	15:25	43.10	4,130,890	25,295	11.6	1,121,770	2	11.2	1,114,680	2	11.6	1,134,130	1	10.9	1,056,510	1	NO	199,150	23.75	6.2
	12/05/09	15:52	40.40	4,164,520	33,011	11.3	1,131,700	1	11.1	1,124,290	1	11.4	1,143,720	1	9.3	1,064,900	2	YES	202,200	22.75	6.1
	12/06/09	16:15		4,190,670	25,739		1,138,850	0		1,131,240	0		1,150,770	1		1,071,260	2	NO	202,200	21.75	7.8
	12/07/09	15:10	41.60	4,217,120	27,700	11.2	1,146,080	2	11.1	1,138,250	2	11.1	1,157,810	1	10.5	1,077,910	1	NO	202,200	20.75	7.8
22	12/08/09	18:15	43.80	4,244,230	24,024	11.8	1,154,200	1	11.8	1,146,090	0	12.1	1,165,560	1	10.3	1,084,800	2	YES	205,260	35.00	NA
	12/09/09	16:20	43.90	4,265,960	23,616	11.4	1,159,970	1	11.3	1,151,870	0	11.8	1,171,340	1	11.4	1,090,090	1	NO	205,260	34.25	7.1
	12/10/09	15:45	41.90	4,293,640	28,370	11.3	1,167,370	3	11.2	1,159,120	2	11.3	1,178,740	1	10.6	1,097,130	1	NO	205,260	33.25	7.4
	12/11/09	16:00		4,320,640	26,722		1,175,360	0		1,166,840	1		1,186,350	1		1,104,010	2	YES	208,300	32.25	7.6
	12/12/09	16:00		4,352,350	31,710		1,183,990	1		1,175,330	0		1,194,970	2		1,111,750	3	NO	208,300	31.50	4.8
	12/13/09	16:22	42.00	4,377,100	24,378	11.4	1,190,770	3	11.2	1,181,910	3	11.3	1,201,650	1	10.4	1,117,940	0	NO	208,300	30.75	6.2
	12/14/09	16:00		4,405,210	28,546		1,199,190	1		1,189,990	0		1,209,620	1		1,124,970	3	YES	211,330	29.75	7.3
	12/15/09	16:30	42.44	4,429,440	23,736	11.4	1,205,820	1	11.3	1,196,600	2	11.6	1,216,340	1	10.8	1,130,850	2	NO	211,330	29.00	6.3
	12/16/09	16:00		4,457,000	28,146		1,213,270	1		1,203,850	1		1,223,640	1		1,137,700	3	NO	211,330	28.00	7.4
	12/17/09	16:00		4,483,110	26,110		1,221,100	0		1,211,380	0		1,231,050	0		1,144,350	2	YES	214,360	27.25	5.9
23	12/18/09	15:10		4,508,170	25,961		1,227,850	0		1,218,090	1		1,237,850	0		1,150,480	2	NO	214,360	26.75	4.1
	12/19/09	16:27		4,535,100	25,563		1,234,210	0		1,225,110	1		1,244,900	0		1,157,330	2	NO	214,360	26.00	5.7
	12/20/09	16:00		4,562,030	27,445		1,242,810	0		1,232,710	1		1,252,480	0		1,164,450	2	YES	217,400	25.00	7.6
	12/21/09	16:50		4,588,640	25,717		1,249,820	0		1,239,780	0		1,259,480	1		1,171,070	2	NO	217,400	24.00	7.7
	12/22/09	16:30		4,614,460	26,184		1,256,640	0		1,246,610	1		1,266,290	1		1,177,540	2	NO	217,400	23.00	7.9
	12/23/09	16:05	84.30	4,638,000	23,956	21.4	1,263,940	1	21.7	1,253,730	0	22.7	1,273,240	0	22.4	1,183,990	0	YES	220,440	22.25	6.5
	12/24/09	16:00	83.80	4,666,060	28,158	21.7	1,271,110	2	21.7	1,260,960	2	22.2	1,280,750	2	21.9	1,191,410	1	NO	220,440	21.50	5.5
	12/25/09	15:55	83.00	4,692,680	26,713	22.1	1,278,110	3	21.8	1,267,890	2	22.0	1,287,810	2	21.2	1,198,260	2	NO	220,440	20.50	7.7
	12/26/09	15:38	84.70	4,719,490	27,130	22.1	1,286,240	1	21.6	1,275,650	1	22.5	1,295,510	1	22.2	1,205,510	1	YES	223,470	35.00	NA
	12/27/09	16:06	83.50	4,749,300	29,241	22.2	1,294,000	3	21.5	1,283,200	2	22.1	1,303,340	2	21.5	1,213,180	0	NO	223,470	34.25	5.2
24	12/28/09	15:25	83.20	4,773,640	25,053	22.4	1,300,610	4	21.7	1,289,610	3	21.9	1,309,860	3	21.1	1,219,510	1	NO	223,470	33.50	6.3
	12/29/09	16:00	85.80	4,795,770	21,605	21.7	1,307,630	1	22.2	1,296,290	1	23.0	1,316,350	1	22.7	1,225,540	0	YES	226,520	32.25	11.6
	12/30/09	16:10		4,828,700	32,703		1,316,030	0		1,304,760	0		1,325,070	1		1,234,120	2	NO	226,520	31.25	6.2
	12/31/09	16:00		4,866,240	37,803		1,325,940	1		1,314,570	0		1,334,980	1		1,243,740	2	NO	226,520	30.25	5.5
	01/01/10	16:35		4,905,590	38,416		1,337,560	0		1,325,760	0		1,346,040	1		1,254,110	2	YES	229,560	29.00	6.5
	01/02/10	16:00		4,942,810	38,147		1,347,070	0		1,335,360	0		1,346,030	1		1,263,800	1	NO	229,560	27.75	6.9
	01/03/10	17:00		4,988,450	43,814		1,359,150	0		1,347,260	0		1,368,090	1		1,278,370	2	NO	229,560	26.25	6.7
	01/04/10	16:18	84.00	5,027,180	39,894	22.6	1,370,330	1	22.6	1,358,210	0	21.8	1,378,850	0	20.3	1,285,470	1	YES	232,590	25.00	6.6
	01/05/10	16:08	84.10	5,055,810	28,830	22.3	1,377,950	2	22.2	1,365,850	2	21.9	1,386,360	2	20.8	1,292,530	1	NO	232,590	24.00	7.2
	01/06/10	16:25		5,085,910	29,749		1,385,860	0		1,373,730	0		1,394,200	1		1,299,950	2	NO	232,590	23.00	6.8
25	01/07/10	16:25		5,114,620	28,710		1,394,520	0		1,382,170	0		1,402,480	1		1,307,610	2	YES	235,640	21.75	8.9
	01/08/10	16:02	84.10	5,143,970	29,826	21.8	1,402,020	2	21.8	1,389,770	1	22.4	1,410,450	2	22.0	1,315,430	1	NO	235,640	21.00	5.2
	01/09/10	16:00		5,173,020	29,090		1,409,550	0		1,397,250	0		1,418,090	1		1,322,850	2	NO	235,640	35.00	NA
	01/10/10	15:40		5,202,260	29,652		1,418,360	1		1,405,780	0		1,426,480	1		1,330,710	2	YES	238,690	34.00	7.0
	01/11/10	16:10		5,232,570	29,691		1,426,090	1		1,413,590	0		1,434,610	1		1,338,690	2	NO	238,690	33.00	6.8
	01/12/10	18:00		5,277,640	41,871		1,437,920	0		1,425,330	0		1,446,540	1		1,350,270	2	NO	238,690	31.50	6.8
	01/13/10	17:55		5,307,240	29,703		1,446,380	0		1,433,660	0		1,454,830	1		1,358,060	2	YES	241,730	30.75	5.2
	01/14/10	16:00		5,332,660	27,626		1,453,070	0		1,440,390	0		1,461,590	0		1,364,390	3	NO	241,730	30.00	6.0
	01/15/10	16:00		5,359,250	26,590		1,460,080	0		1,447,390	0		1,468,630	1		1,371,130	2	NO	241,730	29.25	5.8
	01/16/10	16:00	84.90	5,391,400	32,150	21.4	1,469,290	1	22.3	1,456,410	1	22.9	1,477,770	1	21.8	1,379,810	0	YES	244,790	28.25	6.4
26	01/17/10	15:30		5,420,420	29,637		1,476,710	0		1,464,010	1		1,485,650	1		1,387,310	2	NO	244,790	27.25	7.1
	01/18/10	16:00		5,452,750	31,670		1,485,120	0		1,472,400	0		1,494,330	1		1,395,630	2	NO	244,790	26.00	7.9
	01/19/10	15:30	85.00	5,482,460	30,342	22.7	1,493,630	1	22.8	1,480,800	1	22.4	1,502,830	1	21.2	1,403,630	0	YES	247,820	25.00	6.9
	01/20/10	17:20	85.00	5,510,790	26,319	22.5	1,5														

**Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet
(Continued)**

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ⁽⁴⁾ (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
31	02/05/10	16:00		5,967,030	29,620		1,625,230	0		1,611,630	1		1,634,520	1		1,529,420	2	NO	263,050	24.25	6.9
	02/06/10	16:00		5,996,620	29,590		1,634,000	0		1,620,250	0		1,643,100	1		1,537,530	2	YES	266,110	23.25	6.9
	02/07/10	16:00		6,024,590	27,970		1,641,120	1		1,627,460	0		1,650,610	1		1,544,930	2	NO	266,110	22.50	5.5
	02/08/10	16:00		6,049,840	25,250		1,647,680	0		1,634,020	0		1,657,330	1		1,551,470	2	NO	266,110	21.75	6.1
	02/09/10	15:05	85.20	6,075,980	27,178	21.3	1,655,540	1	22.0	1,641,710	1	23.0	1,664,940	1	22.8	1,558,610	1	YES	269,160	21.00	5.9
	02/10/10	16:03		6,101,790	24,811		1,662,130	0		1,648,420	1		1,671,930	1		1,565,480	2	NO	269,160	20.25	6.0
	02/11/10	16:03		6,126,740	24,950		1,668,600	0		1,654,900	0		1,678,580	0		1,571,970	2	NO	269,160	25.25	NA
	02/12/10	16:00		6,152,760	26,074		1,676,430	0		1,662,520	0		1,686,050	0		1,579,080	2	YES	272,220	24.25	7.9
	02/13/10	16:00		6,177,790	25,030		1,682,760	0		1,669,050	0		1,692,770	1		1,585,660	2	NO	272,220	23.50	6.1
	02/14/10	16:10	83.50	6,209,480	31,471	21.8	1,690,930	4	21.8	1,677,300	3	22.0	1,701,180	2	21.6	1,593,910	1	NO	272,220	22.50	6.5
32	02/15/10	16:30		6,235,600	25,762		1,698,810	0		1,684,870	0		1,708,740	1		1,601,140	2	YES	275,270	21.50	7.8
	02/16/10	16:00		6,259,640	24,551		1,705,110	0		1,690,970	0		1,715,130	1		1,607,480	2	NO	275,270	20.75	6.4
	02/17/10	16:00	84.10	6,286,910	27,270	22.5	1,712,390	3	21.7	1,698,020	3	22.1	1,722,390	3	21.6	1,614,620	2	NO	275,270	19.75	7.5
	02/18/10	16:10	87.60	6,312,020	24,937	22.2	1,719,690	1	23.2	1,705,150	2	23.5	1,729,570	1	22.2	1,621,500	1	YES	278,320	29.00	NA
	02/19/10	15:05	84.50	6,339,460	28,737	21.9	1,726,730	1	22.3	1,712,440	2	22.6	1,736,980	1	21.7	1,628,540	0	NO	278,320	28.25	5.6
	02/20/10	16:00		6,366,390	25,939		1,733,720	0		1,719,470	0		1,744,090	1		1,635,390	2	NO	278,320	27.25	7.6
	02/21/10	16:00	84.90	6,397,740	31,350	22.5	1,742,680	1	22.5	1,728,410	1	22.2	1,753,030	1	21.4	1,643,800	0	YES	281,370	26.25	6.5
	02/22/10	16:30		6,424,900	26,606		1,749,920	0		1,735,590	1		1,760,130	1		1,650,620	2	NO	281,370	25.25	7.5
	02/23/10	16:50		6,447,300	22,093		1,755,930	0		1,741,500	2		1,766,010	1		1,656,260	1	NO	281,370	24.75	4.6
	02/24/10	15:30	85.60	6,475,210	29,552	22.6	1,764,110	1	22.9	1,749,570	1	22.6	1,773,990	1	21.6	1,663,700	0	YES	284,400	23.75	7.3
33	02/25/10	16:00		6,500,780	25,048		1,770,860	1		1,756,330	0		1,780,710	1		1,670,100	2	NO	284,400	22.75	8.0
	02/26/10	16:00		6,530,610	29,830		1,778,820	0		1,764,220	0		1,788,570	2		1,677,640	2	NO	284,400	21.75	6.9
	02/27/10	15:50	84.60	6,556,770	26,343	22.6	1,786,610	1	22.2	1,771,870	1	22.3	1,796,100	0	21.7	1,684,780	1	YES	287,430	21.00	5.9
	02/28/10	16:00	84.40	6,582,630	25,682	22.7	1,793,510	2	22.2	1,778,640	2	22.2	1,802,880	2	21.5	1,691,420	1	NO	287,430	20.25	5.9
	03/01/10	14:50	83.40	6,612,290	31,175	22.5	1,801,480	2	22.0	1,786,420	3	21.9	1,810,630	2	21.2	1,698,910	1	NO	287,430	25.25	NA
	03/02/10	16:00		6,639,100	25,567		1,808,770	1		1,793,490	0		1,817,640	0		1,705,670	1	NO	287,430	24.50	5.7
	03/03/10	16:00		6,663,780	24,680		1,815,890	0		1,800,510	0		1,824,570	1		1,712,160	1	YES	290,470	23.75	6.2
	03/04/10	16:00		6,689,500	25,720		1,822,660	1		1,807,370	0		1,831,450	1		1,718,580	2	NO	290,470	22.75	8.0
	03/05/10	16:00		6,716,810	27,310		1,830,470	0		1,815,100	0		1,839,180	0		1,725,890	2	YES	293,530	22.00	5.6
	03/06/10	16:00	85.00	6,746,480	29,670	22.3	1,838,230	2	22.4	1,823,000	2	22.6	1,847,140	2	21.6	1,733,470	0	NO	293,530	21.00	6.9
34	03/07/10	16:00		6,776,430	29,950		1,846,150	1		1,830,850	0		1,855,030	0		1,740,120	2	NO	293,530	29.00	NA
	03/08/10	15:30		6,802,850	26,982	21.2	1,854,270	0	21.9	1,838,700	1	22.9	1,862,690	0	22.7	1,748,170	2	YES	296,580	28.00	7.8
	03/09/10	15:30	84.90	6,828,100	25,250	21.8	1,860,620	2	22.0	1,845,200	2	22.6	1,869,470	2	22.5	1,754,900	0	NO	296,580	27.00	8.1
	03/10/10	15:35	84.20	6,853,690	25,501	22.1	1,867,280	3	21.9	1,851,880	2	22.3	1,876,300	3	21.8	1,761,630	1	NO	296,580	26.25	6.0
	03/11/10	15:15	85.00	6,879,110	25,778	21.3	1,874,990	1	22.0	1,861,330	0	23.3	1,883,640	0	22.4	1,768,860	0	YES	299,640	25.25	8.1
	03/12/10	16:00		6,905,150	25,251		1,881,620	0		1,866,080	1		1,890,720	0		1,775,670	2	NO	299,640	24.50	5.9
	03/13/10	15:30		6,932,720	28,157		1,888,800	0		1,873,250	0		1,898,110	0		1,782,790	2	NO	299,640	23.75	5.6
	03/14/10	16:00	84.30	6,967,350	33,923	22.5	1,898,620	0	22.4	1,883,010	1	22.3	1,907,890	1	21.4	1,791,950	2	YES	302,680	22.50	7.4
	03/15/10	15:07	84.00	6,993,960	27,627	22.5	1,905,700	0	22.2	1,890,040	0	22.0	1,914,900	0	21.2	1,798,690	1	NO	302,680	21.50	7.7
	03/16/10	16:00	81.70	7,039,650	44,068	22.3	1,918,030	4	21.6	1,902,140	3	21.4	1,926,970	4	20.3	1,810,210	3	NO	302,680	20.00	6.7
35	03/17/10	16:21	85.60	7,064,800	24,789	21.1	1,925,920	1	22.1	1,909,690	1	22.3	1,934,290	1	22.9	1,818,610	0	YES	305,750	19.25	6.1
	03/18/10	16:00		7,093,840	29,470		1,933,210	0		1,917,170	1		1,942,090	0		1,824,550	2	NO	305,750	30.00	NA
	03/19/10	16:00		7,116,770	22,930		1,939,130	0		1,923,120	1		1,948,250	1		1,830,520	1	NO	305,750	29.25	6.7
	03/20/10	16:00	84.90	7,148,860	32,090	22.5	1,948,260	0	22.5	1,932,220	1	22.3	1,957,440	1	21.3	1,839,130	0	YES	308,790	28.00	8.0
	03/21/10	16:30		7,177,620	28,173		1,955,900	0		1,939,790	0		1,964,920	0		1,846,310	2	NO	308,790	27.00	7.1
	03/22/10	16:15		7,203,620	26,274		1,962,890	0		1,946,640	0		1,971,820	0		1,852,820	2	NO	308,790	26.25	5.9
	03/23/10	16:37	84.50	7,230,680	26,653	21.1	1,971,030	2	22.0	1,954,550	1	23.1	1,979,590	1	22.8	1,860,030	0	YES	311,840	25.00	9.5
	03/24/10	16:00	85.60	7,253,270	23,186	21.7	1,976,830	2	22.1	1,960,510	1	22.9	1,985,840	2	22.5	1,866,140	0	NO	311,840	24.25	6.8
	03/25/10	15:00		7,282,460	30,459		1,984,350	0		1,968,080	1		1,993,650	0		1,873,720	2	NO	311,840	23.50	5.3
	03/26/10	15:42	85.80	7,307,140	23,981	21.3	1,991,920	1	22.0	1,975,450	0	23.4	2,000,960	0	23.1	1,880,540	0	YES	314,900	22.75	6.2
36	03/27/10	15:30	84.80	7,334,600	27,691	21.8	1,998,850	2	21.9	1,982,510	2	22.7	2,008,400	1	22.4	1,887,890	1	NO	314,900	21.75	7.5
	03/28/10	16:00		7,365,120	29,897		2,006,740	0		1,990,370	0		2,016,530	0		1,895,790	2	NO	314,900	20.75	6.7
	03/29/10	16:00		7,392,310	27,190		2,019,450	0		1,998,020	0		2,024,280	0		1,903,130	1	YES	317,940	3	

**Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet
(Continued)**

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ^(a) (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
41	04/15/10	16:00	84.00	7,893,330	28,850	22.6	2,151,160	3	22.1	2,132,440	2	22.0	2,160,440	2	21.0	2,033,190	2	NO	333,190	29.00	7.1
	04/16/10	16:00		7,925,070	31,740		2,160,730	0		2,140,690	1		2,169,470	1		2,041,540	2	YES	336,270	28.00	6.5
	04/17/10	16:00	85.50	7,954,180	29,110	21.7	2,168,040	2	22.1	2,149,200	3	22.9	2,177,360	2	22.4	2,049,300	0	NO	336,270	27.00	7.0
	04/18/10	16:12		7,990,910	36,426		2,177,580	1		2,158,750	0		2,187,100	1		2,058,790	1	NO	336,270	26.00	5.6
	04/19/10	16:00		8,020,620	29,960		2,186,250	0		2,167,280	0		2,195,560	1		2,066,750	1	YES	339,320	25.00	6.9
	04/20/10	15:10	83.70	8,055,910	36,559	22.4	2,195,600	1	21.6	2,176,430	2	22.0	2,204,890	2	21.4	2,075,920	1	NO	339,320	24.00	5.8
	04/21/10	16:00		8,082,820	26,007		2,202,760	0		2,183,390	1		2,211,900	1		2,082,740	1	NO	339,320	23.00	7.6
	04/22/10	16:00		8,109,870	27,050		2,210,550	0		2,191,020	0		2,219,500	1		2,089,960	0	YES	342,360	22.00	7.6
	04/23/10	15:36	84.90	8,140,870	31,525	22.1	2,218,590	2	22.3	2,199,250	2	22.5	2,227,810	2	21.5	2,097,850	1	NO	342,360	21.25	5.0
	04/24/10	15:15	83.10	8,171,980	31,570	22.1	2,226,760	3	21.9	2,207,440	3	22.0	2,236,060	3	20.9	2,105,730	3	NO	342,360	20.00	8.2
42	04/25/10	15:45	84.50	8,201,770	29,182	21.1	2,235,580	1	21.8	2,216,140	2	22.8	2,244,710	1	22.7	2,113,850	0	YES	345,410	19.00	6.9
	04/26/10	15:35	84.00	8,229,380	27,803	21.6	2,242,570	2	21.7	2,223,290	2	22.5	2,252,140	2	21.9	2,121,200	1	NO	345,410	29.00	NA
	04/27/10	16:00		8,258,470	28,594		2,250,070	0		2,230,760	1		2,259,820	1		2,128,640	2	NO	345,410	28.25	5.3
	04/28/10	16:00		8,283,960	25,490		2,257,350	0		2,238,050	1		2,267,140	0		2,135,600	1	YES	348,480	27.25	8.0
	04/29/10	16:00		8,337,860	53,900		2,264,160	1		2,245,070	1		2,274,280	1		2,142,400	1	NO	348,480	26.50	2.9
	04/30/10	14:50	83.20	8,350,590	13,380	22.1	2,271,310	3	21.7	2,252,230	2	22.0	2,281,560	2	21.0	2,149,390	1	NO	348,480	25.75	12.1
	05/01/10	15:45		8,364,930	13,812		2,278,950	1		2,259,800	1		2,289,210	1		2,156,600	1	YES	351,530	24.75	14.3
	05/02/10	16:10	88.10	8,393,910	28,485	22.3	2,286,430	2	22.4	2,267,420	2	23.1	2,297,010	2	22.2	2,164,050	2	NO	351,530	23.75	7.1
	05/03/10	16:02	85.10	8,422,670	28,921	22.4	2,293,940	3	22.1	2,274,910	2	22.6	2,304,670	3	21.6	2,171,400	3	NO	351,530	23.00	5.3
	05/04/10	16:20	85.60	8,450,740	27,723	21.2	2,302,500	1	22.0	2,283,160	1	22.9	2,312,830	1	22.9	2,179,010	1	YES	354,750	22.00	7.3
43	05/05/10	16:00		8,479,120	28,780		2,309,560	1		2,290,410	1		2,320,400	0		2,186,530	0	NO	354,750	21.00	7.2
	05/06/10	16:00		8,505,930	26,810		2,316,460	1		2,297,350	1		2,327,520	1		2,193,520	2	NO	354,750	20.25	5.7
	05/07/10	16:00	85.40	8,537,710	31,780	21.8	2,325,370	1	22.7	2,306,230	1	22.9	2,336,450	1	21.4	2,202,040	1	YES	357,960	19.25	6.5
	05/08/10	15:15	83.60	8,570,250	33,590	21.8	2,333,810	3	22.0	2,314,850	2	22.2	2,345,200	3	21.1	2,210,290	1	NO	357,960	28.00	NA
	05/09/10	16:00		8,599,200	28,073		2,341,400	0		2,322,450	0		2,352,840	1		2,217,590	2	NO	357,960	27.00	7.1
	05/10/10	16:00	84.90	8,632,090	32,890	21.7	2,350,650	1	22.4	2,331,650	1	22.6	2,362,060	0	21.5	2,226,310	0	YES	361,170	32.00	NA
	05/11/10	16:00		8,655,280	23,190		2,356,670	0		2,337,770	1		2,368,240	0		2,232,230	1	NO	361,170	31.25	6.6
	05/12/10	16:00		8,681,430	26,150		2,363,500	1		2,344,610	0		2,375,150	1		2,238,890	1	NO	361,170	30.50	5.9
	05/13/10	16:00		8,707,780	26,350		2,371,080	0		2,352,110	1		2,382,660	1		2,246,040	0	YES	364,380	29.75	5.8
	05/14/10	16:00		8,734,890	27,110		2,378,080	0		2,359,250	1		2,389,910	1		2,252,940	1	NO	364,380	28.75	7.6
44	05/15/10	16:00		8,763,120	28,230		2,385,430	0		2,366,610	1		2,397,360	1		2,260,120	1	NO	364,380	28.00	5.4
	05/16/10	15:30	85.20	8,789,890	27,340	21.5	2,395,470	1	21.6	2,376,360	1	22.5	2,400,150	1	22.4	2,269,470	0	YES	367,610	27.00	7.7
	05/17/10	16:00		8,829,150	38,459		2,403,460	0		2,384,300	0		2,415,380	1		2,277,650	2	NO	367,610	26.00	5.2
	05/18/10	16:00		8,857,760	28,610		2,410,910	1		2,391,590	0		2,422,650	0		2,284,950	1	NO	367,610	25.00	7.2
	05/19/10	16:30		8,885,360	27,037		2,418,890	0		2,399,520	1		2,430,790	1		2,292,390	1	YES	371,300	23.75	9.3
	05/20/10	16:00		8,912,250	27,462		2,425,830	0		2,406,560	0		2,437,780	1		2,299,060	2	NO	371,300	22.75	7.6
	05/21/10	16:00		8,939,120	26,870		2,432,850	0		2,413,550	1		2,444,740	0		2,305,730	1	NO	371,300	22.00	5.7
	05/22/10	16:00		8,970,210	31,090		2,442,130	0		2,422,660	1		2,453,740	1		2,314,130	1	YES	375,120	21.00	6.6
	05/23/10	15:50	83.70	9,009,400	39,464	21.5	2,451,920	2	21.3	2,432,560	2	22.0	2,464,070	2	21.2	2,324,270	2	NO	375,120	20.00	5.2
	05/24/10	16:05		9,039,260	29,552		2,459,720	0		2,440,230	0		2,471,880	0		2,331,780	0	NO	375,120	29.00	NA
45	05/25/10	16:00	86.30	9,071,090	31,941	21.8	2,469,260	1	21.8	2,449,380	1	22.8	2,481,000	1	22.4	2,340,310	1	YES	378,900	28.00	6.4
	05/26/10	16:00		9,099,460	28,370		2,476,470	0		2,456,520	1		2,488,380	1		2,347,590	0	NO	378,900	27.25	5.4
	05/27/10	16:00		9,136,300	36,840		2,486,150	1		2,465,930	1		2,497,980	1		2,356,900	1	NO	378,900	26.25	5.6
	05/28/10	16:00	84.50	9,172,420	36,120	21.1	2,496,930	2	21.4	2,476,320	1	22.6	2,508,280	1	22.4	2,366,590	0	YES	382,700	25.00	7.1
	05/29/10	16:00	85.20	9,203,010	30,590	22.0	2,504,650	2	21.9	2,484,080	2	22.6	2,516,420	2	22.1	2,374,570	2	NO	382,700	24.00	6.7
	05/30/10	15:55	82.50	9,246,930	44,073	21.9	2,516,180	4	21.2	2,495,410	3	21.5	2,528,000	3	20.5	2,385,750	3	NO	382,700	22.50	7.0
	05/31/10	16:00		9,282,770	35,716		2,526,910	0		2,505,760	0		2,537,670	0		2,395,230	1	YES	386,500	21.25	7.1
	06/01/10	16:57	85.60	9,304,570	20,970	21.7	2,533,570	0	21.9	2,512,570	2	22.6	2,545,280	2	22.3	2,402,300	3	NO	386,500	20.75	4.7
	06/02/10	16:00		9,340,670	37,588		2,541,630	0		2,520,600	1		2,553,530	1		2,410,280	0	NO	386,500	34.00	NA
	06/03/10	16:00	85.00	9,371,240	30,570	21.0	2,550,940	1	21.8	2,529,710	0	22.8	2,562,520	0	22.7	2,418,660	1	YES	390,300	33.00	6.7
46	06/04/10	16:00		9,400,910	29,670		2,558,380	1		2,537,270	2		2,570,410	1		2,426,490	1	NO	390,300	32.00	6.9
	06/05/10	15:30		9,426,860	26,502		2,565,100	0		2,543,970	2		2,577,280	1		2,433,180	1	NO	390,300	31.25	5.9
	06/06/10	16:00	84.60	9,455,370	27,928	21.0	2,573,780	0	21.8	2,552,420	0	22.7	2,585,670	1	22.6	2,441,050	1	YES	394,020	30.25	7.2
	06/07/10	16:00		9,483,470	28																

**Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet
(Continued)**

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ^(a) (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
51	06/23/10	16:00		9,944,930	26,620		2,704,960	0		2,683,800	1		2,719,550	1		2,571,110	0	NO	409,730	27.75	5.8
	06/24/10	16:20		9,976,180	30,822		2,714,260	0		2,692,930	1		2,728,490	1		2,579,420	1	YES	412,720	26.75	6.6
	06/25/10	16:00		10,005,460	29,692		2,722,390	0		2,701,230	2		2,736,850	1		2,587,630	1	YES	415,670	25.75	7.0
	06/26/10	15:00	84.40	10,030,570	26,202	21.8	2,728,800	2	22.0	2,707,790	1	21.9	2,743,440	1	22.4	2,594,380	2	NO	415,670	25.00	6.1
	06/27/10	16:00	83.60	10,063,050	31,181	22.2	2,737,310	3	22.0	2,716,300	3	21.7	2,751,890	3	21.5	2,602,870	3	NO	415,670	23.75	7.9
	06/28/10	16:00		10,101,720	38,670		2,748,620	0		2,727,280	1		2,762,600	1		2,613,070	1	YES	418,550	22.50	6.6
	06/29/10	16:30	84.10	10,132,410	30,064	21.5	2,756,450	3	21.3	2,735,210	3	22.6	2,771,120	3	22.3	2,621,600	3	NO	418,550	21.25	8.3
	06/30/10	16:00		10,159,050	27,207		2,763,200	0		2,741,850	1		2,778,070	1		2,628,360	1	NO	418,550	20.50	5.8
	07/01/10	16:00		10,184,960	25,910		2,770,860	0		2,749,420	1		2,785,710	1		2,635,530	1	YES	422,230	32.50	NA
	07/02/10	15:50	85.60	10,213,620	28,860	22.5	2,778,290	2	22.7	2,757,000	2	22.3	2,793,100	2	21.7	2,642,670	1	NO	422,230	31.50	7.2
52	07/03/10	16:35		10,249,150	34,453		2,787,880	0		2,766,530	1		2,802,490	1		2,651,730	0	NO	422,230	30.00	8.7
	07/04/10	15:15	83.80	10,284,240	37,154	20.8	2,798,220	0	21.3	2,776,670	1	23.1	2,812,450	1	22.1	2,661,020	0	YES	425,150	29.00	5.8
	07/05/10	15:30	84.40	10,313,610	29,067	21.7	2,805,680	2	21.6	2,784,160	2	22.9	2,820,500	2	22.0	2,668,830	3	NO	425,150	28.00	7.0
	07/06/10	16:10		10,345,000	30,542		2,813,840	0		2,792,190	1		2,828,910	1		2,676,880	0	NO	425,150	27.00	6.5
	07/07/10	16:30	83.40	10,392,810	47,155	22.2	2,827,320	1	22.5	2,805,690	1	21.9	2,842,380	1	21.0	2,689,590	1	YES	428,830	25.00	8.6
	07/08/10	16:00		10,421,840	29,648		2,834,990	0		2,813,390	1		2,849,960	1		2,696,840	0	NO	428,830	24.00	7.1
	07/09/10	16:00		10,457,740	35,900		2,844,580	0		2,822,880	1		2,859,440	1		2,705,860	2	NO	428,830	23.00	5.7
	07/10/10	13:00		10,481,870	27,577		2,852,220	0		2,830,060	1		2,866,230	1		2,712,130	2	YES	431,610	22.00	8.5
	07/11/10	15:50	84.50	10,518,320	32,601	21.6	2,861,310	2	22.1	2,839,630	2	22.8	2,876,190	2	21.9	2,721,610	1	NO	431,610	21.00	5.6
	07/12/10	16:00		10,549,640	31,104		2,869,430	0		2,847,870	1		2,884,640	1		2,729,640	1	NO	431,610	20.00	6.5
53	07/13/10	16:00		10,583,880	34,240		2,879,500	1		2,857,750	1		2,894,420	1		2,738,620	1	YES	434,290	34.00	NA
	07/14/10	16:00		10,610,340	26,460		2,886,040	0		2,864,530	1		2,901,600	1		2,745,810	0	NO	434,290	33.25	5.8
	07/15/10	16:00		10,638,340	28,000		2,893,230	0		2,871,760	1		2,909,130	1		2,753,190	1	NO	434,290	32.25	7.3
	07/16/10	17:15		10,673,270	33,201		2,903,370	1		2,881,760	1		2,919,110	1		2,762,590	1	YES	437,110	31.00	7.3
	07/17/10	15:30		10,699,930	28,757		2,909,990	1		2,888,630	1		2,926,350	1		2,769,800	1	NO	437,110	30.00	7.7
	07/18/10	16:00		10,733,000	32,395		2,918,520	1		2,897,230	1		2,935,220	1		2,778,480	1	NO	437,110	28.75	7.7
	07/19/10	16:03	85.00	10,762,980	29,918	20.6	2,927,570	1	22.9	2,906,050	1	23.2	2,943,920	1	23.3	2,786,590	0	YES	439,840	28.00	5.1
	07/20/10	16:00		10,787,890	24,962		2,935,010	1		2,913,700	1		2,951,700	1		2,794,200	1	YES	444,070	27.00	8.2
	07/21/10	16:00		10,817,970	30,080		2,943,030	0		2,921,600	1		2,959,740	1		2,802,160	0	NO	444,070	26.00	6.8
	07/22/10	15:55		10,843,940	26,060		2,949,400	0		2,928,440	1		2,966,630	1		2,808,880	1	NO	444,070	25.00	7.9
54	07/23/10	15:55	83.80	10,875,960	32,020	20.1	2,959,360	0	21.6	2,938,220	1	21.0	2,976,190	0	22.0	2,817,790	1	YES	448,290	24.00	6.4
	07/24/10	15:45	84.00	10,904,410	28,649	21.1	2,966,350	2	21.7	2,945,530	2	22.7	2,983,950	2	22.5	2,825,560	2	NO	448,290	23.00	7.2
	07/25/10	16:00		10,939,480	34,708		2,975,360	0		2,954,640	1		2,993,370	1		2,834,780	1	NO	448,290	22.00	5.8
	07/26/10	16:25		10,978,100	37,961		2,987,100	0		2,966,090	1		3,004,730	1		2,845,330	1	YES	452,520	20.75	6.6
	07/27/10	16:00		11,004,100	26,459		2,993,460	1		2,972,760	1		3,011,830	1		2,852,490	0	NO	452,520	34.25	NA
	07/28/10	15:45		11,030,990	27,173		3,000,320	0		2,979,730	1		3,019,100	2		2,859,650	0	NO	452,520	33.50	5.7
	07/29/10	16:00	84.50	11,060,140	28,849	20.1	3,009,490	1	21.9	2,988,720	0	23.1	3,027,990	0	23.7	2,867,930	1	YES	456,750	32.25	8.8
	07/30/10	16:00		11,088,090	27,950		3,016,260	0		2,995,900	1		3,035,600	1		2,876,110	1	NO	456,750	31.50	5.5
	07/31/10	16:00		11,114,900	26,810		3,023,050	1		3,002,880	1		3,042,860	1		2,882,790	1	NO	456,750	30.75	5.7
	08/01/10	16:00		11,149,440	34,540		3,033,410	0		3,013,260	1		3,053,230	1		2,892,580	1	YES	460,980	29.75	5.9
56	08/02/10	16:00		11,174,810	25,370		3,039,620	0		3,019,830	1		3,060,180	1		2,899,540	0	NO	460,980	29.00	6.1
	08/03/10	16:30	83.00	11,203,380	27,987	21.6	3,046,950	3	21.9	3,027,320	3	22.4	3,067,980	3	21.9	2,907,230	4	NO	460,980	28.00	7.2
	08/04/10	15:45	86.00	11,231,570	29,099	20.2	3,055,810	0	22.2	3,036,020	0	23.8	3,076,530	0	24.0	2,915,100	1	YES	465,180	27.00	7.3
	08/05/10	18:00	84.40	11,262,690	28,453	21.1	3,063,390	2	21.9	3,044,080	1	22.9	3,085,110	1	22.9	2,923,750	2	NO	465,180	26.00	6.6
	08/06/10	16:00		11,289,170	28,887		3,070,080	0		3,050,950	1		3,092,210	1		2,930,780	0	NO	465,180	25.00	7.7
	08/07/10	16:00		11,330,930	41,760		3,082,430	0		3,063,270	1		3,104,470	1		2,942,350	1	YES	469,420	23.75	6.1
	08/08/10	16:00		11,365,380	34,450		3,090,890	0		3,072,190	1		3,113,860	1		2,951,790	1	NO	469,420	22.50	7.4
	08/09/10	16:00	83.00	11,394,120	28,740	21.7	3,098,410	3	21.7	3,079,860	3	22.2	3,121,780	3	21.6	2,959,580	3	NO	469,420	21.50	7.1
	08/10/10	16:00	82.70	11,428,790	34,670	19.9	3,108,900	0	21.8	3,090,200	0	23.1	3,131,990	0	23.6	2,969,110	1	YES	473,630	20.50	5.9
	08/11/10	16:00		11,453,940	25,150		3,114,990	1		3,096,680	1		3,138,820	1		2,976,000	0	NO	473,630	19.50	8.2
57	08/12/10	16:00	83.80	11,482,570	28,630	21.5	3,122,230	2	22.0	3,104,110	2	22.6	3,146,530	2	22.2	2,983,640	3	NO	473,630	35.00	NA
	08/13/10	16:00		11,516,600	34,030		3,132,400	0		3,114,210	1		3,156,510	1		2,993,320	1	YES	477,860	34.00	6.0
	08/14/10	16:00		11,543,320	26,720		3,138,900	0		3,121,160	1		3,163,850	1		3,000,650	0	NO	477,860	33.25	5.8
	08/15/10	16:00		11,577,580	34,260		3,147,650	0		3,130,110	1		3,173,110	1							

**Table A-1. U.S. EPA Arsenic Demonstration Project at Waynesville, IL - Daily System Operation and Operator Labor Log Sheet
(Continued)**

Week No.	Time and System Effluent Meter					System Service Parameters												Backwash		Oxidant Addition	
	Date	Time	System Effluent Meter			Tank A			Tank B			Tank C			Tank D			Back-wash	Estimated Cum. Totalizer ^(a) (gal)	NaMnO4 Level (gal)	NaMnO4 Dosage (mg/L)
			Flow rate (gpm)	Cum. totalizer (gal)	Daily Treated (gpd)	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP	Flow rate (gpm)	Cum. Totalizer (gal)	ΔP				
61	08/31/10	16:00		12,058,210	28,640		3,278,900	0		3,263,740	0		3,309,850	1		3,142,750	0	YES	503,160	20.00	7.2
	09/01/10	15:15	83.30	12,088,370	31,133	20.9	3,286,240	2	21.8	3,271,590	1	22.9	3,318,190	1	22.8	3,151,190	1	NO	503,160	35.25	NA
	09/02/10	16:00		12,115,940	26,735		3,293,290	0		3,278,790	2		3,325,700	1		3,158,580	1	NO	503,160	34.50	5.6
	09/03/10	16:45	85.20	12,143,650	26,870	21.2	3,301,340	1	22.7	3,286,880	1	23.2	3,333,870	1	22.9	3,166,360	0	YES	507,350	33.50	7.4
	09/04/10	16:00		12,169,710	26,901		3,307,890	0		3,293,750	1		3,340,900	2		3,173,300	1	NO	507,350	32.75	5.9
	09/05/10	15:15	82.50	12,202,780	34,137	21.9	3,316,550	3	21.8	3,302,530	2	22.2	3,349,900	2	21.6	3,182,110	2	NO	507,350	31.75	6.2
	09/06/10	16:00	83.70	12,235,460	31,690	20.0	3,326,470	2	21.7	3,312,500	1	23.1	3,359,810	0	23.5	3,191,450	0	YES	511,570	30.75	6.3
	09/07/10	16:10		12,263,620	27,966		3,333,390	0		3,319,810	1		3,367,540	1		3,199,210	1	NO	511,570	28.75	14.6
	09/08/10	16:00		12,290,370	26,937		3,340,230	0		3,326,810	1		3,374,810	1		3,206,390	1	NO	511,570	28.25	3.8
	09/09/10	15:50		12,317,210	27,028		3,348,910	0		3,335,270	0		3,383,070	1		3,214,010	0	YES	515,830	27.25	7.6
62	09/10/10	16:30	84.00	12,347,770	29,734	21.0	3,356,340	2	21.9	3,343,300	2	23.0	3,391,610	2	23.1	3,222,680	1	NO	515,830	34.00	NA
	09/11/10	14:00		12,372,200	27,271		3,362,480	1		3,349,620	1		3,398,170	1		3,229,200	1	NO	515,830	33.25	6.3
	09/12/10	16:00	83.70	12,405,720	30,942	20.0	3,372,710	2	21.7	3,359,700	1	23.0	3,408,220	2	23.0	3,238,800	1	YES	520,060	32.50	4.6
	09/13/10	16:00		12,434,730	29,010		3,379,740	0		3,367,170	1		3,416,110	1		3,246,810	0	NO	520,060	31.50	7.1
	09/14/10	16:00		12,461,990	27,260		3,386,690	0		3,374,320	1		3,423,540	1		3,254,180	0	NO	520,060	30.25	9.4
	09/15/10	16:00		12,490,260	28,270		3,395,670	0		3,383,140	1		3,432,190	1		3,262,260	0	YES	524,290	29.25	7.3
	09/16/10	16:00		12,517,260	27,000		3,402,170	0		3,390,190	1		3,439,650	1		3,269,860	1	NO	524,290	28.50	5.7
	09/17/10	16:15		12,544,080	26,544		3,408,930	0		3,397,210	1		3,446,980	1		3,277,190	0	NO	524,290	27.75	5.7
	09/18/10	15:30	85.10	12,572,070	28,893	20.1	3,417,650	1	22.2	3,405,920	0	23.6	3,455,620	0	24.2	3,285,340	0	YES	528,520	26.75	7.3
	09/19/10	16:00		12,603,800	31,082		3,425,390	1		3,414,210	1		3,464,390	1		3,294,210	1	NO	528,520	25.75	6.5

NA = not available

System in parallel configuration.

Green highlighted columns indicate calculated values.

Yellow highlighted rows indicate days with no backwash.

(a) From approximately November 11 through December 2, 2009, backwash totalizer not functioning properly.

APPENDIX B
ANALYTICAL DATA

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL

Sampling Date		07/15/09			08/05/09						08/19/09 ^(b)			09/02/09					
Sampling Location		IN	AO	TT	IN	AO	TA	TB	TC	TD	IN	AO	TT	IN	AO	TA	TB	TC	TD
Parameter	Unit																		
Alkalinity (as CaCO ₃)	mg/L	634	641	627	579	579	574	574	579	586	595	592	588	578	583	576	576	565	578
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	3.9	4.1	4.0	3.6	3.6	3.6	3.6	3.8	3.7	3.5	3.6	3.5	3.4	3.4	3.4	3.3	3.3	3.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.4	0.5	0.5	-	-	-	-	-	-	0.4	0.5	0.5	-	-	-	-	-	-
Sulfate	mg/L	<0.1	<0.1	<0.1	-	-	-	-	-	-	<0.1	0.1	<0.1	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Phosphorus (as P)	µg/L	131	106	19.2	141	135	40.3	34.6	35.8	36.1	100	92.1	22.1	95.3	90.3	16.4	15.2	16.1	18.4
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	23.0	23.0	22.8	22.4	22.2	21.8	22.3	21.6	21.4	21.2	21.0	21.1	21.9	22.7	21.9	21.7	22.2	22.2
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	36.0	11.0	0.3	36.0	7.2	0.3	0.6	0.6	1.0	38.0	9.8	2.4	35.0	11.0	0.3	1.0	0.6	0.8
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	8.5	7.9	7.8	-	-	-	-	-	-	8.2	7.8	7.5	-	-	-	-	-	-
pH	S.U.	NA ^(a)	NA ^(a)	NA ^(a)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Temperature	°C	NA ^(a)	NA ^(a)	NA ^(a)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DO	mg/L	2.5	3.4	2.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ORP	mV	42	373	154	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	601	551	548	-	-	-	-	-	-	457	429	432	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	294	272	272	-	-	-	-	-	-	238	209	211	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	308	279	276	-	-	-	-	-	-	218	220	222	-	-	-	-	-	-
As (total)	µg/L	33.5	30.4	4.6	45.2	42.3	0.5	0.2	0.1	0.4	39.9	33.4	2.8	36.2	34.9	1.4	0.8	0.5	1.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	28.9	3.6	2.5	-	-	-	-	-	-	35.3	33.3	2.4	-	-	-	-	-	-
As (particulate)	µg/L	4.6	26.8	2.1	-	-	-	-	-	-	4.7	<0.1	0.4	-	-	-	-	-	-
As(III)	µg/L	22.8	0.6	0.6	-	-	-	-	-	-	30.4	2.8	1.2	-	-	-	-	-	-
As(V)	µg/L	6.1	3.0	1.9	-	-	-	-	-	-	4.9	30.5	1.2	-	-	-	-	-	-
Fe (total)	µg/L	2,474	2,275	150	2,368	2,230	<25	<25	<25	<25	2,239	1,610	<25	2,103	2,000	<25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	2,463	<25	<25	-	-	-	-	-	-	2,299	1,953	<25	-	-	-	-	-	-
Mn (total)	µg/L	37.6	2,766	108	32.5	2,270	13.4	64.3	60.7	75.9	46.9	2,266	77.8	108	2,965	20.4	101	93.5	108
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	33.4	1,239	13.8	-	-	-	-	-	-	46.2	2,724	81.7	-	-	-	-	-	-

(a) pH and temperature not measured on 07/15/09.

(b) B bottle collected by operator, but sample appeared to be unfiltered. Speciation performed with C bottle collected at Battelle laboratory.

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL (Continued)

Sampling Date		09/15/09			09/30/09						10/15/09			10/28/09					
Sampling Location		IN	AO	TT	IN	AO	TA	TB	TC	TD	IN	AO	TT	IN	AO	TA	TB	TC	TD
Parameter	Unit																		
Alkalinity (as CaCO ₃)	mg/L	548 -	548 -	563 -	542 582	575 590	580 582	573 577	571 571	573 578	582 -	578 -	595 -	552 -	554 -	536 -	535 -	538 -	516 -
Ammonia (as N)	mg/L	3.7 -	3.7 -	3.8 -	3.5 3.7	3.6 3.6	3.5 3.6	3.6 3.6	3.5 3.6	3.6 3.7	3.6 -	3.6 -	3.6 -	3.8 -	4.0 -	4.0 -	4.0 -	3.9 -	3.9 -
Fluoride	mg/L	0.4	0.5	1.2	-	-	-	-	-	-	0.4	0.5	0.7	-	-	-	-	-	-
Sulfate	mg/L	<0.1	<0.1	0.2	-	-	-	-	-	-	<0.1	0.1	0.1	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Phosphorus (as P)	µg/L	94.1 -	69.1 -	429 -	99.9 104	101 104	12.6 14.0	13.9 14.0	14.9 15.1	15.3 15.8	102 -	91.2 -	18.5 -	93.1 -	94.5 -	<10 -	<10 -	<10 -	<10 -
Silica (as SiO ₂)	mg/L	21.6 -	21.4 -	21.7 -	21.8 21.7	21.9 21.9	21.5 21.7	21.3 21.8	21.4 21.5	21.6 21.8	20.0 -	19.6 -	19.5 -	22.5 -	22.3 -	22.3 -	22.3 -	22.3 -	21.9 -
Turbidity	NTU	37.0 -	7.4 -	1.7 -	32.0 32.0	12.0 11.0	1.0 0.5	1.9 0.7	1.0 0.4	0.4 0.6	36.0 -	9.2 -	0.4 -	33.0 -	9.9 -	1.9 -	0.9 -	0.6 -	1.7 -
TOC	mg/L	8.3	8.2	7.9	-	-	-	-	-	-	7.2	6.8	6.7	-	-	-	-	-	-
pH	S.U.	9.1	8.2	8.2	NA	NA	NA	NA	NA	NA	9.6	8.8	9.1	NA	NA	NA	NA	NA	NA
Temperature	°C	14.4	14.4	14.4	NA	NA	NA	NA	NA	NA	14.4	13.3	13.3	NA	NA	NA	NA	NA	NA
DO	mg/L	0.8	1.1	0.6	NA	NA	NA	NA	NA	NA	0.6	1.9	0.9	NA	NA	NA	NA	NA	NA
ORP	mV	-71.6	477	30.9	NA	NA	NA	NA	NA	NA	-33.7	413	9.9	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	498	493	495	-	-	-	-	-	-	528	510	488	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	260	261	259	-	-	-	-	-	-	283	281	294	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	239	232	236	-	-	-	-	-	-	245	229	194	-	-	-	-	-	-
As (total)	µg/L	40.1 -	28.6 -	5.2 -	45.0 44.6	42.6 43.2	3.0 3.0	2.7 2.7	2.7 2.7	2.5 2.5	38.7 -	35.6 -	4.3 -	37.8 -	38.0 -	2.7 -	2.5 -	2.5 -	2.2 -
As (soluble)	µg/L	38.1	22.6	3.5	-	-	-	-	-	-	32.2	3.5	3.3	-	-	-	-	-	-
As (particulate)	µg/L	2.0	5.9	1.7	-	-	-	-	-	-	6.5	32.1	1.0	-	-	-	-	-	-
As(III)	µg/L	28.5	15.5	1.4	-	-	-	-	-	-	29.6	<0.1	0.8	-	-	-	-	-	-
As(V)	µg/L	9.6	7.1	2.0	-	-	-	-	-	-	2.6	3.4	2.5	-	-	-	-	-	-
Fe (total)	µg/L	2,186 -	1,594 -	86 -	2,086 1,948	2,028 1,972	<25 <25	<25 <25	<25 <25	<25 <25	2,112 -	2,329 -	<25 -	1,954 -	2,009 -	<25 -	<25 -	<25 -	<25 -
Fe (soluble)	µg/L	2,119	1,097	<25	-	-	-	-	-	-	2,474	107	<25	-	-	-	-	-	-
Mn (total)	µg/L	26.3 -	173 -	119 -	25.0 24.0	2,409 2,409	32.9 32.6	144 142	135 126	123 123	22.2 -	1,762 -	58.1 -	25.0 -	2,271 -	31.8 -	88.6 -	92.0 -	84.7 -
Mn (soluble)	µg/L	26.2	159	94.9	-	-	-	-	-	-	23.8	685	60.8	-	-	-	-	-	-

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL (Continued)

Sampling Date		11/11/09			12/02/09						12/14/09			01/11/10					
Sampling Location		IN	AO	TT	IN	AO	TA	TB	TC	TD	IN	AO	TT	IN	AO	TA	TB	TC	TD
Parameter	Unit																		
Alkalinity (as CaCO ₃)	mg/L	593	597	602	571	604	602	596	591	578	578	587	584	633	629	624	574	596	594
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	3.7	3.6	3.6	3.7	3.7	3.7	3.8	3.6	3.7	3.7	3.8	3.6	3.6	3.6	3.5	3.6	3.6	3.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.4	0.3	0.6	-	-	-	-	-	-	0.6	0.6	0.8	-	-	-	-	-	-
Sulfate	mg/L	<0.1	0.1	<0.1	-	-	-	-	-	-	<0.1	0.1	<0.1	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Phosphorus (as P)	µg/L	85.4	83.7	51.6	88.2	93.0	10.3	10.2	10.5	12.2	86.5	93.5	22.3	89.8	93.1	<10	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	22.8	22.6	22.4	22.8	23.1	22.5	22.3	22.8	22.9	22.7	22.0	22.0	23.3	23.3	22.9	23.2	23.1	22.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	35.0	8.9	1.9	32.0	11.0	0.3	0.3	0.5	0.3	34.0	11.0	0.2	33.0	9.0	0.3	0.2	0.5	<0.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	8.0	7.7	7.4	-	-	-	-	-	-	7.8	7.1	6.8	-	-	-	-	-	-
pH	S.U.	8.0	8.0	7.9	NA	NA	NA	NA	NA	NA	8.0	7.4	7.7	NA	NA	NA	NA	NA	NA
Temperature	°C	14.4	14.4	14.4	NA	NA	NA	NA	NA	NA	13.9	14.4	14.4	NA	NA	NA	NA	NA	NA
DO	mg/L	0.8	1.4	0.7	NA	NA	NA	NA	NA	NA	1.6	1.3	0.6	NA	NA	NA	NA	NA	NA
ORP	mV	NA ^(a)	NA ^(a)	NA ^(a)	NA	NA	NA	NA	NA	NA	-23.1	453	339	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	406	430	441	-	-	-	-	-	-	370	497	497	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	170	187	193	-	-	-	-	-	-	200	277	277	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	236	243	248	-	-	-	-	-	-	170	220	220	-	-	-	-	-	-
As (total)	µg/L	36.4	37.2	3.3	35.4	37.6	2.3	2.1	2.1	2.1	32.3	36.0	2.5	27.5	25.3	2.1	1.9	1.7	1.6
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	35.6	5.0	3.0	-	-	-	-	-	-	33.2	3.9	2.6	-	-	-	-	-	-
As (particulate)	µg/L	0.8	32.2	0.3	-	-	-	-	-	-	<0.1	32.1	<0.1	-	-	-	-	-	-
As(III)	µg/L	25.4	0.8	0.8	-	-	-	-	-	-	26.4	0.5	0.5	-	-	-	-	-	-
As(V)	µg/L	10.2	4.2	2.2	-	-	-	-	-	-	6.7	3.4	2.0	-	-	-	-	-	-
Fe (total)	µg/L	2,511	2,634	<25	2,184	2,257	<25	<25	<25	<25	2,060	2,406	<25	2,177	2,192	25	<25	<25	<25
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	2,570	124	<25	-	-	-	-	-	-	2,032	43	<25	-	-	-	-	-	-
Mn (total)	µg/L	24.1	2,033	67.7	24.4	2,212	23.7	115	106	83.0	26.8	2,003	70.0	25.2	2,149	29.2	23.8	56.7	95.1
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	23.9	754	64.9	-	-	-	-	-	-	27.1	691	72.2	-	-	-	-	-	-

(a) Readings not accurately recorded.

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL (Continued)

Sampling Date		01/25/10			02/10/10						02/24/10			03/10/10					
Sampling Location		IN	AO	TT	IN	AO	TA	TB	TC	TD	IN	AO	TT	IN	AO	TA	TB	TC	TD
Parameter	Unit																		
Alkalinity (as CaCO ₃)	mg/L	625	625	609	634	636	636	618	623	627	608	617	581	604	618	607	611	614	614
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	3.8	3.9	2.9	3.8	3.8	3.6	3.7	3.7	3.8	4.1	4.3	1.5	4.0	4.0	4.1	4.0	3.9	3.9
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.4	0.4	6.0 ^(a)	-	-	-	-	-	-	0.4	1.6	16.1 ^(c)	-	-	-	-	-	-
Sulfate	mg/L	<0.1	0.1	0.3	-	-	-	-	-	-	<0.1	<0.1	0.5	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	0.1	-	-	-	-	-	-
Phosphorus (as P)	µg/L	106	99.3	4,008 ^(a)	27.2	27.0	<10	<10	<10	<10	76.0	79.1	5,111 ^(c)	80.0	83.9	10.7	<10	<10	<10
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	24.1	24.3	30.4	23.1	22.4	22.3	21.3	22.1	22.3	21.7	22.2	29.1	20.9	21.1	21.0	20.4	20.6	20.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity	NTU	32.0	12.0	4.9	24.0	9.8	0.9	1.1	0.3	0.6	32.0	11.0	2.5	32.0	12.0	3.3	8.6	2.0	1.7
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOC	mg/L	7.8	7.5	7.3	-	-	-	-	-	-	7.5	7.7	7.5	-	-	-	-	-	-
pH	S.U.	7.3	7.7	7.4	NA	NA	NA	NA	NA	NA	7.3	7.5	7.7	NA	NA	NA	NA	NA	NA
Temperature	°C	12.7	13.3	13.4	NA	NA	NA	NA	NA	NA	13.3	13.3	13.3	NA	NA	NA	NA	NA	NA
DO	mg/L	1.5	1.4	0.9	NA	NA	NA	NA	NA	NA	1.0	1.3	0.7	NA	NA	NA	NA	NA	NA
ORP	mV	369 ^(b)	308	473	NA	NA	NA	NA	NA	NA	366 ^(b)	412	483	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	561	529	515	-	-	-	-	-	-	473	470	481	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	325	302	288	-	-	-	-	-	-	250	249	255	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	236	227	227	-	-	-	-	-	-	224	221	226	-	-	-	-	-	-
As (total)	µg/L	26.1	25.5	3.6	27.2	27.0	1.8	1.7	1.7	1.7	35.5	25.3	3.5	25.6	25.4	4.3	3.6	3.0	2.5
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	27.5	4.4	3.5	-	-	-	-	-	-	36.1	2.9	3.7	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	21.1	0.1	-	-	-	-	-	-	<0.1	22.4	<0.1	-	-	-	-	-	-
As(III)	µg/L	32.2	0.9	0.8	-	-	-	-	-	-	27.2	0.6	0.9	-	-	-	-	-	-
As(V)	µg/L	<0.1	3.5	2.7	-	-	-	-	-	-	8.9	2.3	2.8	-	-	-	-	-	-
Fe (total)	µg/L	2,720	2,610	<25	2,285	2,637	<25	<25	<25	<25	1,939	1,945	<25	2,260	2,288	259	199	133	90
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	2,841	147	<25	-	-	-	-	-	-	1,939	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	25.4	2,966	53.0	28.1	2,618	52.7	23.8	17.4	74.0	26.6	2,123	63.1	23.1	2,095	185	158	112	134
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	24.8	1,567	47.2	-	-	-	-	-	-	24.7	786	47.3	-	-	-	-	-	-

(a) Results combined by laboratory reanalysis.

(b) Reading uncharacteristically high; a new ORP probe sent to site for future measurements.

(c) Uncharacteristically high results as also seen on 01/25/10 might have been caused by cross-contamination from post chemical treatment.

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL (Continued)

Sampling Date		03/23/10			04/07/10						04/22/10 ^(c)			05/05/10					
Sampling Location		IN	AO	TT	IN	AO	TA	TB	TC	TD	IN	AO	TA	IN	AO	TA	TB	TC	TD
Parameter	Unit																		
Alkalinity (as CaCO ₃)	mg/L	628	637	588	616	613	607	620	620	613	599	663	649	622	631	624	615	629	617
		-	-	-	651	597	579	606	620	588	-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	3.8	4.3	1.9	3.9	3.9	3.9	3.9	3.8	3.8	4.1	4.4	4.0	4.1	4.1	4.0	4.0	4.1	4.0
		-	-	-	4.2	3.8	4.0	4.0	3.9	3.9	-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.4	0.4	16.9 ^(a)	-	-	-	-	-	-	0.4	0.5	0.7	-	-	-	-	-	-
Sulfate	mg/L	<0.1	<0.1	0.7	-	-	-	-	-	-	<0.1	<0.1	0.1	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	<0.05	-	-	-	-	-	-
Phosphorus (as P)	µg/L	39.0	48.6	6,621 ^(a)	96.6	91.0	10.9	<10	<10	<10	75.3	88.6	42.3	100	91.0	<10	<10	<10	<10
		-	-	-	82.6	85.1	<10	<10	<10	<10	-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	22.6	22.5	29.9	23.5	23.0	22.9	22.5	23.1	23.2	22.1	22.4	22.1	22.3	22.1	21.8	22.0	21.8	22.0
		-	-	-	23.3	23.1	23.1	22.9	22.8	22.9	-	-	-	-	-	-	-	-	-
Turbidity	NTU	40.0	11.0	5.5	31.0	8.6	1.2	0.5	0.3	0.7	35.0	9.7	8.0	35.0	9.0	3.0	1.8	2.5	2.2
		-	-	-	33.0	10.0	4.7	1.3	1.2	2.7	-	-	-	-	-	-	-	-	-
TOC	mg/L	8.9	8.2	7.8	-	-	-	-	-	-	7.9	8.0	7.2	-	-	-	-	-	-
pH	S.U.	6.9	7.3	7.8	NA	NA	NA	NA	NA	NA	7.6	7.4	7.4	NA	NA	NA	NA	NA	NA
Temperature	°C	14.4	14.9	14.5	NA	NA	NA	NA	NA	NA	14.7	14.7	14.9	NA	NA	NA	NA	NA	NA
DO	mg/L	1.9	2.6	0.7	NA	NA	NA	NA	NA	NA	0.7	1.3	1.6	NA	NA	NA	NA	NA	NA
ORP	mV	290 ^(b)	338	515	NA	NA	NA	NA	NA	NA	-61.0	487	121	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	453	470	449	-	-	-	-	-	-	318	277	269	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	246	258	234	-	-	-	-	-	-	104	104	106	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	207	212	214	-	-	-	-	-	-	214	174	163	-	-	-	-	-	-
As (total)	µg/L	24.5	25.1	3.7	29.9	25.0	1.9	1.6	1.7	1.6	33.5	26.6	2.1	28.6	28.2	1.8	1.7	1.8	1.8
		-	-	-	24.2	23.9	1.8	1.6	1.8	1.5	-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	24.7	2.6	3.9	-	-	-	-	-	-	33.4	3.6	2.4	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	22.5	<0.1	-	-	-	-	-	-	0.1	23.0	<0.1	-	-	-	-	-	-
As(III)	µg/L	13.3	0.6	0.7	-	-	-	-	-	-	20.1	0.8	0.6	-	-	-	-	-	-
As(V)	µg/L	11.5	2.0	3.1	-	-	-	-	-	-	13.3	2.9	1.7	-	-	-	-	-	-
Fe (total)	µg/L	2,469	2,511	<25	2,550	2,511	<25	<25	<25	<25	2,254	2,204	<25	2,427	2,237	<25	<25	<25	<25
		-	-	-	2,322	2,381	<25	<25	<25	<25	-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	2,510	37	<25	-	-	-	-	-	-	1,942	32	<25	-	-	-	-	-	-
Mn (total)	µg/L	22.5	1,760	38.0	22.2	1,803	30.5	12.1	34.3	76.2	25.3	1,331	5.2	39.9	3,433	11.1	7.0	36.5	76.2
		-	-	-	21.2	1,973	29.1	11.5	34.6	76.8	-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	23.3	244	33.8	-	-	-	-	-	-	26.3	536	4.9	-	-	-	-	-	-

(a) Uncharacteristically high results as also seen on 01/25/10 and 02/24/10 might have been caused by cross-contamination from post chemical treatment. Corrective actions taken on 04/14/10 to clean, repair, and/or replace chemical injector assemblies for all chemical addition systems.

(b) Uncharacteristically high readings as also seen on 01/25/10 and 02/24/10 confirmed with replacement probe.

(c) Due to possible cross-contamination by post chemical treatment, speciation samples collected at TA (instead of TT) on 04/22/10, 05/19/10, and 09/15/10.

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL (Continued)

Sampling Date		05/19/10 ^(a)			06/09/10						06/15/10			06/30/10					
Sampling Location		IN	AO	TA	IN	AO	TA	TB	TC	TD	IN	AO	TT	IN	AO	TA	TB	TC	TD
Parameter	Unit																		
Alkalinity (as CaCO ₃)	mg/L	610	634	627	614	670	600	641	614	600	603	648	630	608	612	675	697	559	612
		-	-	-	-	-	-	-	-	-	-	-	-	612	612	635	617	599	599
Ammonia (as N)	mg/L	4.2	5.8	4.1	4.2	4.1	4.0	4.1	4.3	4.2	4.2	4.3	<0.05	4.1	4.0	4.0	4.1	4.0	4.0
		-	-	-	-	-	-	-	-	-	-	-	-	4.1	4.1	4.1	4.0	4.0	4.1
Fluoride	mg/L	0.4	0.3	0.4	-	-	-	-	-	-	0.4	0.4	9.3 ^(b)	-	-	-	-	-	-
Sulfate	mg/L	<0.1	<0.1	<0.1	-	-	-	-	-	-	<0.1	<0.1	0.5	-	-	-	-	-	-
Nitrate (as N)	mg/L	<0.05	<0.05	<0.05	-	-	-	-	-	-	<0.05	<0.05	0.2	-	-	-	-	-	-
Phosphorus (as P)	µg/L	70.1	73.4	19.8	108	111	18.7	25.1	27.9	35.6	88.4	87.9	6,627 ^(b)	80.3	25.3 ^(c)	15.0	13.6	12.4	<10
		-	-	-	-	-	-	-	-	-	-	-	-	80.8	80.3	18.9	13.8	12.5	11.1
Silica (as SiO ₂)	mg/L	21.8	22.9	22.6	21.8	21.8	22.5	21.9	21.8	22.1	22.5	22.4	27.8	22.4	22.1	21.7	21.8	21.8	21.4
		-	-	-	-	-	-	-	-	-	-	-	-	19.3	22.5	21.9	21.4	21.9	21.7
Turbidity	NTU	32.0	14.0	6.8	34.0	10.0	1.7	1.2	0.9	0.8	34.0	12.0	0.8	30.0	9.4	1.3	1.2	1.3	2.6
		-	-	-	-	-	-	-	-	-	-	-	-	33.0	9.3	1.5	1.3	0.7	0.9
TOC	mg/L	7.4	8.5	7.5	-	-	-	-	-	-	8.8	8.3	7.7	-	-	-	-	-	-
pH	S.U.	5.7	5.6	7.4	NA	NA	NA	NA	NA	NA	7.0	7.2	7.2	NA	NA	NA	NA	NA	NA
Temperature	°C	13.3	14.4	14.4	NA	NA	NA	NA	NA	NA	14.9	15.8	15.8	NA	NA	NA	NA	NA	NA
DO	mg/L	7.8	2.0	1.2	NA	NA	NA	NA	NA	NA	1.0	1.1	1.1	NA	NA	NA	NA	NA	NA
ORP	mV	-58.5	453	73.0	NA	NA	NA	NA	NA	NA	-44.2	397	754	NA	NA	NA	NA	NA	NA
Total Hardness (as CaCO ₃)	mg/L	508	478	454	-	-	-	-	-	-	504	460	445	-	-	-	-	-	-
Ca Hardness (as CaCO ₃)	mg/L	269	260	250	-	-	-	-	-	-	270	239	229	-	-	-	-	-	-
Mg Hardness (as CaCO ₃)	mg/L	239	218	204	-	-	-	-	-	-	234	221	216	-	-	-	-	-	-
As (total)	µg/L	34.7	24.4	1.8	40.3	40.5	2.7	2.6	3.0	3.1	26.7	26.1	3.8	25.1	11.7 ^(c)	4.6	3.7	3.6	2.8
		-	-	-	-	-	-	-	-	-	-	-	-	23.9	24.1	5.2	3.9	3.5	3.0
As (soluble)	µg/L	35.6	3.2	1.8	-	-	-	-	-	-	28.2	2.7	3.3	-	-	-	-	-	-
As (particulate)	µg/L	<0.1	21.2	<0.1	-	-	-	-	-	-	<0.1	23.4	0.5	-	-	-	-	-	-
As(III)	µg/L	20.3	0.4	0.4	-	-	-	-	-	-	23.5	0.8	0.6	-	-	-	-	-	-
As(V)	µg/L	15.2	2.8	1.5	-	-	-	-	-	-	4.8	1.9	2.8	-	-	-	-	-	-
Fe (total)	µg/L	2,185	2,282	<25	2,448	2,571	<25	<25	<25	<25	2,541	2,358	<25	2,411	85 ^(c)	291	218	188	121
		-	-	-	-	-	-	-	-	-	-	-	-	2,220	2,259	353	248	222	136
Fe (soluble)	µg/L	2,084	33	<25	-	-	-	-	-	-	2,431	<25	<25	-	-	-	-	-	-
Mn (total)	µg/L	34.0	3,273	37.9	24.6	3,981	137	80.6	8.4	32.4	25.6	3,698	72.2	24.9	267 ^(c)	234	167	155	162
		-	-	-	-	-	-	-	-	-	-	-	-	21.7	3,088	349	236	170	158
Mn (soluble)	µg/L	36.7	1,081	30.4	-	-	-	-	-	-	21.3	1,120	47.0	-	-	-	-	-	-

(a) Speciation samples collected at TA (instead of TT) until successful resolution of post treatment cross-contamination issues.

(b) Caused by post treatment cross-contamination.

(c) Samples looked cloudy; reanalyzed with similar results.

Table B-1. Analytical Results from Long-Term Sampling at Village of Waynesville, IL (Continued)

Sampling Date		07/14/10			08/18/10 ^(a)			09/15/10 ^(a)		
Sampling Location		IN	AO	TT	IN	AO	TA	IN	AO	TA
Parameter	Unit									
Alkalinity (as CaCO ₃)	mg/L	571	569	587	584	649	662	625	629	652
		-	-	-	-	-	-	-	-	-
Ammonia (as N)	mg/L	3.8	3.8	<0.05	3.7	3.7	4.3	3.9	3.6	4.2
		-	-	-	-	-	-	-	-	-
Fluoride	mg/L	0.3	0.3	4.3	0.3	0.4	0.3	0.4	0.4	0.4
Sulfate	mg/L	<0.1	<0.1	0.3	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Nitrate (as N)	mg/L	<0.05	<0.05	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Phosphorus (as P)	µg/L	89.2	89.7	3,541	80.2	79.6	10.4	89.4	72.9	15.3
		-	-	-	-	-	-	-	-	-
Silica (as SiO ₂)	mg/L	20.9	21.6	26.5	23.2	22.0	21.2	21.1	21.0	21.2
		-	-	-	-	-	-	-	-	-
Turbidity	NTU	14.0	11.0	0.8	31.0	10.0	5.7	33.0	6.5	5.4
		-	-	-	-	-	-	-	-	-
TOC	mg/L	8.1	7.4	7.2	5.8	7.3	8.8	8.4	7.1	8.1
pH	S.U.	7.0	7.3	6.7	7.3	7.3	7.4	7.1	7.5	7.5
Temperature	°C	14.9	15.0	19.4	14.9	15.2	15.5	15.0	14.7	16.0
DO	mg/L	0.8	1.2	1.0	0.7	1.3	1.2	1.5	1.5	1.3
ORP	mV	386	367	676	-1.8	9.0	34.4	-27	207	180
Total Hardness (as CaCO ₃)	mg/L	519	494	472	477	438	404	520	486	498
Ca Hardness (as CaCO ₃)	mg/L	263	253	244	246	224	209	283	283	296
Mg Hardness (as CaCO ₃)	mg/L	256	241	228	231	214	195	223	197	197
As (total)	µg/L	38.0	35.3	3.0	36.1	29.7	1.7	31.2	41.4	4.5
		-	-	-	-	-	-	-	-	-
As (soluble)	µg/L	40.0	3.5	6.0	24.1	2.1	1.6	27.8	5.0	2.9
As (particulate)	µg/L	<0.1	31.8	<0.1	12.0	27.6	<0.1	3.4	36.4	1.7
As(III)	µg/L	30.5	0.2	0.5	17.6	0.3	0.3	17.1	0.7	0.6
As(V)	µg/L	9.4	3.3	5.6	6.5	1.8	1.4	10.7	4.3	2.3
Fe (total)	µg/L	2,594	2,533	<25	2,508	2,421	31	2,290	2,475	678
		-	-	-	-	-	-	-	-	-
Fe (soluble)	µg/L	2,295	<25	<25	2,097	<25	<25	1,979	40	114
Mn (total)	µg/L	82.5	2,948	49.2	68.0	2,427	10.3	29.8	1,599	57.8
		-	-	-	-	-	-	-	-	-
Mn (soluble)	µg/L	73.6	729	36.9	37.7	26.4	10.5	31.8	488	14.6

(a) Speciation samples collected at TA instead of TT.